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ABSTRACT

Fundamental concepts of the spatial environment, technologies, and applications are presented in this manual prepared for senior officers and key civilian employees. Following basic information on the atmosphere, solar system, and intergalactic space, a detailed review is included of astrodynamics, rocket propulsion, bioastronautics, auxiliary spacecraft survival systems, and atmospheric entry. Subsequently there is an analysis of naval space facilities, and satellite applications, especially those of naval interests, are discussed with a background of launch techniques, spatial data gathering, communications programs, observation techniques, measurements by geodetic and navigation systems. Included is a description of space defense and future developments of both national and international space programs. Moreover, commercial systems are mentioned, such as the 85-pound Early Bird (Intelsat I), Intelsat II series, global Intelsat III series, and Soviet-made "Molniya" satellites. The total of 29 men and one woman orbiting the earth in 1961-67 are tabulated in terms of their names, flight series, launching dates, orbit designations, orbiting periods, stand-up periods, and extra vehicular activity records. Besides numerous illustrations, a list of significant space launches and a glossary of special terms are included in the manual appendices along with two tables of frequency band designation. (CC)

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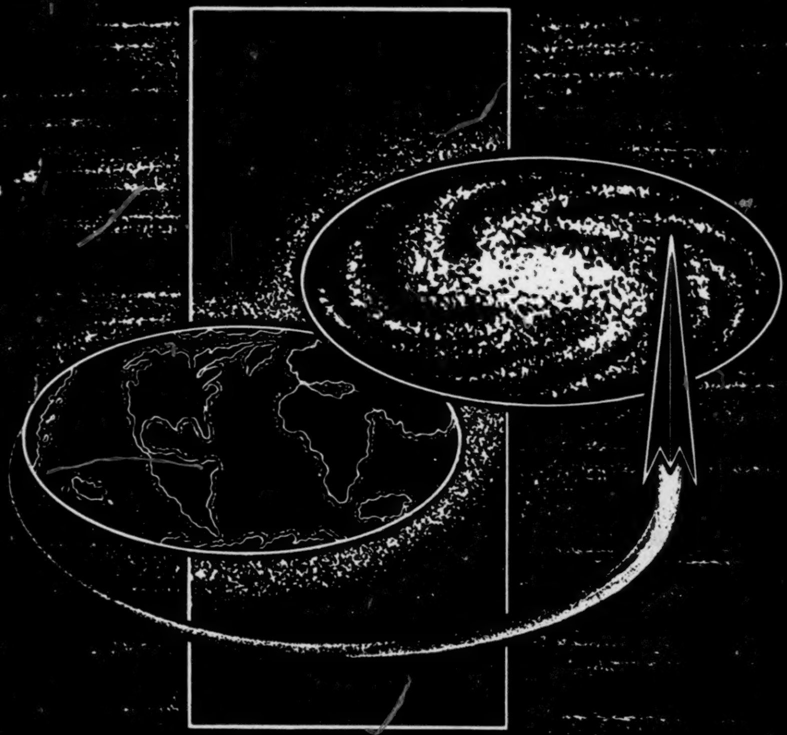

NAVY SPACE AND ASTRONAUTICS ORIENTATION

1967

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PREFACE

This orientation manual on space and astronautics has been prepared primarily for use in the officer correspondence course program of the Bureau of Naval Personnel. It was written by the instructor staff of the Space and Astronautics Orientation Course (SAOC), Naval Missile Center, Point Mugu, California, with the SAOC Officer-in-Charge, Commander R. G. Herron (PH.D) serving as Author/Editor. Its content is based largely on lectures developed by the SAOC staff. Principal contributors, in addition to Commander Herron, were LT J.F. Bott, USNR; LT R. L. Hamm, MC, USN; LCDR W. G. Harker, USNR; LCDR R. A. Hess, USN; LCDR C. A. Oleson, USN; Mr. H. A. Skoog, Aerospace Engineer; and Captain A. D. Thompson, USMC. This contribution to Navy training by Commander Herron and his staff, which was in addition to full-time duty teaching and administering the Space and Astronautics Orientation Course at Point Mugu, is gratefully acknowledged.

Additionally, the technical review assistance given by the Naval Air Systems Command and the technical and policy guidance and direction given by the Director, Astronautics Division, OPNAV contributed materially to the successful production of this Navy manual on space and astronautics.

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2

The Navy's Policy On Space Systems

"It is the policy of the Navy to use DOD satellites, national satellites, or commercial satellites as supporting systems ashore and afloat where these systems are determined to be advantageous and effective. Additionally, the policy is to develop and use satellites in those cases where no other satellite system will satisfy unique Naval requirements and to make these systems available to the other services."

Chief of Naval Operations
Director, Astronautics Division
OPNAV

CONTENTS

CHAPTER Page

1. INTRODUCTION 1

2. THE ATMOSPHERE 3
   The Air Ocean 3
   Early Investigations 4
   Current Knowledge 5
      Troposphere 6
      Stratosphere 6
      Ionosphere 8
      Exosphere 11

3. THE SOLAR SYSTEM 15
   Background 15
   Sun 16
   Planets 17
   Mercury 17
   Venus 18
   Earth 18
   Moon 18
   Mars 19
   Asteroids 20
   Jupiter 20
   Saturn 21
   Uranus 21
   Neptune 22
   Pluto 22
   Comets 22

4. THE UNIVERSE 23

5. ASTRODYNAMICS 27
   General 27
   Fundamental Laws 27
   Orbital Mechanics 28
      Analysis 28
      Establishing Orbits 30
      Changing Orbits 32
      Escape Velocity. 32
   Interplanetary Flights 34

4

CHAPTER Page

5. ASTRODYNAMICS (Con't.)

- Orbit Determination . . . 34
  - Observations . . . 34
  - Orbital Elements . . . 35
  - Orbital Computations . . . 38
  - Space Rendezvous . . . 39

6. ROCKET PROPULSION . . . 41

- General . . . 41
- Chemical Rockets . . . 41
  - Liquid Propellant Rockets . . . 44
  - Solid Propellant Rockets . . . 44
  - Program Status . . . 48
  - Next Generation . . . 51
  - Hybrid Rockets . . . 51
- Nuclear Rockets . . . 52
  - General . . . 52
  - Rover . . . 52
  - Design Problems . . . 53
  - Test Problems . . . 54
- KIWI . . . 55
- NERVA . . . 56
  - Rift . . . 56
  - Future . . . 56
- Electric Rockets . . . 57
  - General . . . 57
  - Electric Rockets . . . 58
  - Electrothermal . . . 59
  - Electromagnetic . . . 60
  - Electrostatic . . . 60
  - Program Status . . . 61
  - Next Generation . . . 61
- Advanced Rockets . . . 62
  - Cavity Reactors . . . 63
  - Nuclear Explosions . . . 65
  - Fusion Reactors . . . 66
  - Photon Rockets . . . 68
  - Solar Sailing . . . 69

7. BIOASTRONAUTICS . . . 71

- General . . . 71
- Respiration . . . 73
- Weightlessness . . . 75
- Radiation . . . 78
- Temperature Regulation . . . 79
- Spacecraft Contamination . . . 79
- Extra Vehicular Activity (EVA) . . . 80
- Food . . . 82
- Waste Control . . . 83
- Psychological Factors . . . 83

CHAPTER Page

8. AUXILIARY SYSTEMS 85

General 85
Conversion Techniques 85
SNAP 88
Solar 92
Batteries 93
Fuel Cells 94
Summary 94
Communications, Tracking, and Guidance 95
  General 95
  Communications 95
  Radio Range Factors 96
  Tracking 98
  Guidance and Control 99
  Interplanetary Travel 100
  Navigation Equipment 101
  Navigation Methods 102

9. ATMOSPHERIC ENTRY 103

General 103
Deceleration and Heating 104
Cooling Techniques 104
Maneuvers 106
Project Status 108
Future 109

10. NAVAL SPACE FACILITIES 111

Naval Space Facilities 113
  Naval Observatory (Washington, D.C.) 113
  Naval Research Laboratory (Washington, D.C.) . . . 114
    Satellite Research 114
    Rocket Astronomy 114
    Radio Astronomy 114
  Naval Medical Research Institute (Bethesda, Md.) . 115
  Naval Ordnance Laboratory (White Oak, Md.) 116
  Naval Weapons Laboratory (Dahlgren, Va.) 117
  Aerospace Crew Equipment Laboratory (Philadelphia, Pa.) 117
  Naval Air Development Center (Johnsville, Pa.) . . 118
  Naval Avionics Facility (Indianapolis, Indiana) . . . 118
  Naval Aerospace Medical Institute (Pensacola, Fla.) 118
  Naval Ordnance Test Station (China Lake, Calif.) . . 120
  Naval Missile Center (Point Mugu, California) . . . 121
  Naval Electronics Laboratory (San Diego, Calif.) . . 121

11. LAUNCH TECHNIQUES 123

Land Launch 124
Water Launch 128
Air Launch 132

CHAPTER Page

12. DATA GATHERING IN SPACE 135
    General 135
    Scientific Probes. 136
    Satellite Programs 138
    Explorers 138
    VanGuard 139
    Interplanetary Explorers 139
    Orbiting Astronomical Observatory (OAO) 140
    Orbiting Solar Observatory (OSO) 140
    Orbiting Geophysical Observatory (OGO) 141
    Pegasus 141
    Biosatellites 142
    Discoverer 142
    SOLRAD 142

13. SATELLITE COMMUNICATIONS 143
    General 143
    Satellites Types 145
    Commercial Systems. 147
    Military Systems 148

14. SATELLITE OBSERVATIONS 151
    Meteorology Satellite Observations 151
    NIMBUS 152
    TOS 153
    Improved TOS 155
    Synchronous Operational Meteorological
        Satellite System 155
    Naval Applications 156
        Operational Aspects 158
        Technological Aspects 159
        Present Status 159

15. MEASUREMENTS FROM SPACE 161
    Geodetic Satellites 161
        General 161
        Geometrical 164
        Geophysical 166
        Program Status (June 1967) 168
    Navigation Satellites 171
        General 171
        Doppler Principle 172
        The Satellite System 174
        Usage by the Fleet 176
    AN/SRN-9 177
        The Ground Network 178
        Tracking 178
        Computer Operations 179
        Injection 179

CHAPTER Page

16. SPACE DEFENSE 181

Naval Space Surveillance System 181
NAVSPASUR Subsystems 182
Data Processing 183
Fleet Use 184

17. THE FUTURE 189

NASA 189

APPENDIX

I. Condensed Listing of Significant Space Launches 199
II. Glossary 203

8

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

9

CHAPTER 1

INTRODUCTION

In October of 1957 the beeping sounds of Sputnik I announced to the world in tones all could understand that mankind had entered the Space Age. Since then the fields of space and astronautics have grown at a rate that confuses the average bystander and astounds the active practitioner. Within a decade space technology has accumulated a list of achievements (see Appendix I) that is unparalleled in the history of man. Understandingly, then, any attempt such as this to report the progress of this productive period will suffer from incompleteness and obsolescence of material as scientific progress outspeeds the pen. Yet, it is necessary for thinking men, both civilian and military, to be aware of the effects of space technology today so that they can better plan for tomorrow.

This planning for tomorrow is of crucial concern to the military who have the responsibility to defend our national way of life whenever it is threatened. It was not strange, therefore, that the Navy undertook studies in the late fifties and early sixties to determine how the Navy should utilize the new technology of space. From these studies came a recommendation that "an orientation course be established to acquaint senior officers and key civilian employees of the Navy Department with fundamental astronautic concepts and space programs."

In keeping with this recommendation the Navy's Space and Astronautics Orientation Course (SAOC) was established in 1960 at the Naval Missile Center, Point Mugu, California, by the Chief of Naval Operations to provide orientation in fundamental astronautics and space programs to support and enhance the Navy's ability to carry out its assigned mission. Since commencement of courses in 1961, SAOC has presented classified briefings to over 25,000 officers and civilian personnel of the Department of Defense. The SAOC lectures which have evolved form the basis of this unclassified manual. The aim of this manual is to provide the reader with information on space and astronautics so that he may now, or in the future, be able to do a better job for the Navy and the nation.

To accomplish this aim, the text material has been grouped into three main categories: (1) the environment of space, (2) the technologies of space, and (3) the applications of space.

The environment of space is discussed first commencing with the atmosphere (Chapter Two), proceeding through the solar system (Chapter Three), and outwards into the intergalactic space of the universe (Chapter Four). These chapters present basic information on the "Ocean of Stars" deemed necessary to highlight the spatial environment that differs radically from our daily mode of existence.

In the second category, that of space technologies, our treatment begins with a review of the basic physical laws concerning "sailing among the stars" (Astrodynamics — Chapter Five). We follow in Chapter Six with a detailed discussion of propulsion techniques covering space flight fundamentals including chemical, nuclear, and electrical rockets and advanced propulsion techniques. Since man is not at all times content to stay at home and let instruments be his only eyes, we next examine the hazards of manned space flights (Bioastronautics — Chapter Seven). Auxiliary spacecraft survival systems are so essential that we consider power supplies, communications, tracking and guidance, and space navigation in Chapter Eight. Since returning home is perhaps the most vital maneuver for the space traveler, we conclude our section on technologies with atmospheric entry (Chapter Nine). This state-of-the-art review in space technology equips us to consider space applications directed primarily towards Navy interests.

We commence the space applications section in Chapter Ten with an analysis of naval policy, interests, and organizations including a survey of the contributions made by Naval laboratories. The convenient classification of satellite applications into the five functional areas (data gather-

10

ing, communications, observations, reference points in space, and space defense) forms the frame of reference for the detailed discussion of Navy programs in space. As a preface to these applications, launch techniques (including water launch) are treated in Chapter Eleven. Such a study of booster vehicles is considered a natural starting point for putting payloads into space. In Chapter Twelve we consider applications of data gathering and call attention to the Navy's long-time interest and successes in this field. Chapter Thirteen highlights satellite communications for both military and peacetime applications. Chapter Fourteen on satellite observations of Earth points out that, besides cooperating in a tri-service approach to meteorology, the Navy is also exploring sensor developments for keeping watch over the ocean areas of the world. Using satellites as reference points in space is discussed in Chapter Fifteen where detailed descriptions are provided of geodetic satellites and the Navy's Navigation Satellite System. The navigation satellite is typical of the manner in which space systems today are serving the fleet effectively. Space defense which includes being able to do something about enemy satellites as well as knowing where they are is discussed in Chapter Sixteen. Chapter Seventeen is an extrapolation into the future of both national and international space programs. The concluding few paragraphs of the chapter preview future military applications in space. A glossary is included as Appendix Two to cushion the jargon of the space generation.

Throughout this unclassified manual, wherever appropriate, emphasis is placed upon the close relationships existing between space operations and Navy operations because the Navy, justifiably, is interested in space operations primarily only insofar as space applications can contribute to the Navy's ability to carry out its assigned military mission. In brief, the Navy will use space when it helps them do their Navy job better.

With the introduction now completed, fasten your seat belts, relax and prepare to enjoy the scenery as you wend on an intellectual journey through space.

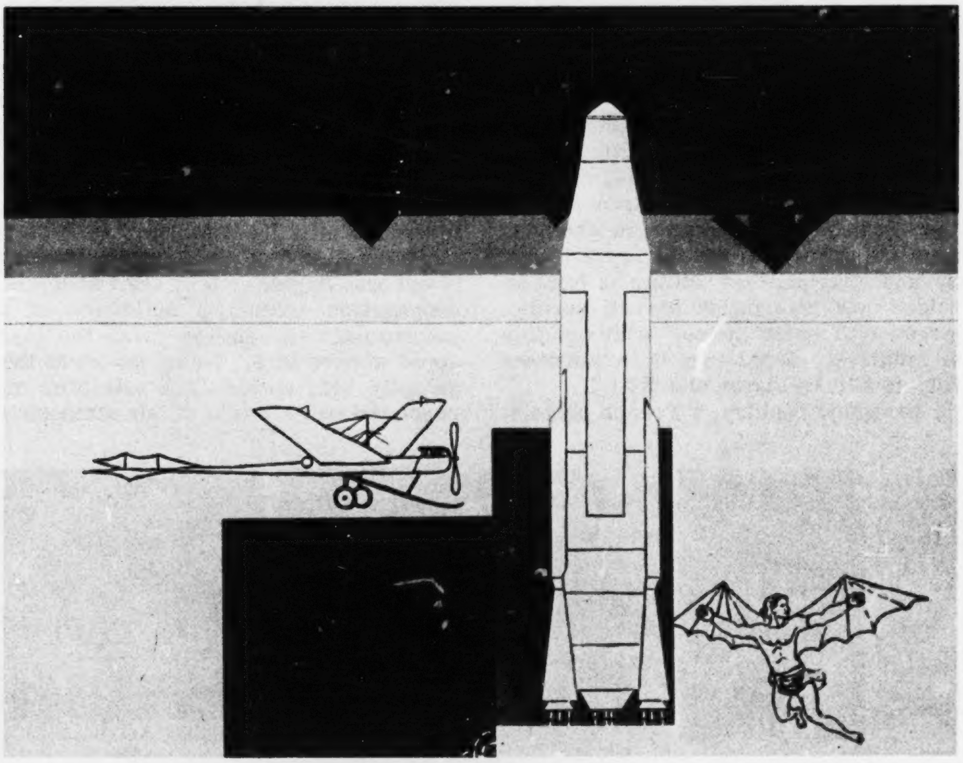
CHAPTER 2

THE ATMOSPHERE

THE AIR OCEAN

No part of the Earth is more essential to life than our atmosphere. Without it, life as we know it could not exist. Yet most of us go about our daily routine without fully realizing that we live at the bottom of a vast sea of tasteless, odorless, and colorless gases. This sea of gases dominates all of our activities. What we eat, wear, and produce are all influenced by climate . . .a condition determined by the atmospheric responses to the Sun or other energy processes. The atmosphere also serves as a blanket to protect us from the burning effects of too severe sunlight in the daytime and the freezing effects of too much loss of heat during the night.

At the bottom of this atmosphere, sometimes called the air ocean, the gases exert a pressure of about fifteen pounds per square inch. Man and the other organisms which crawl about on the floor of this air ocean have adapted themselves to withstand this mighty force. Man is unique, however, in that he has not only succeeded in overcoming his natural environment but now routinely swims in this air ocean and beyond into space.



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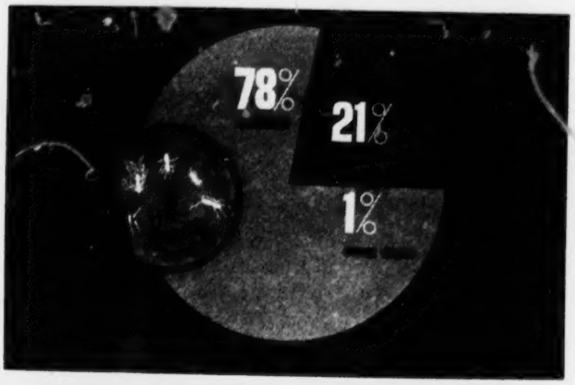


What we call the air ocean is really a mixture of gases. By volume it is composed of about 21% oxygen and 78% nitrogen, with the remaining one percent made up of carbon dioxide, hydrogen, helium and traces of the rare gases such as neon, argon, krypton, and xenon. Because of the air circulation, the proportions of these gases remains remarkably uniform up to levels of about 50 miles. Water vapor was not mentioned in the foregoing list because while it is abundant in the atmosphere, it does vary widely in volume, from over 5% in the air overlying a tropical ocean to fractional percents in cold, dry polar continental air masses. Also included in the atmosphere are variable amounts of dust, bacteria, carbon particles and other solid matter. Nearly all of this has been blown up from the surface of the Earth, but some of it has been actually added from meteors and the dust of outer space! (It has been estimated that 10,000 tons of meteoric dust fall on the earth's atmosphere annually, but this represents a negligible deposit over the earth's surface).

•••••••

EARLY INVESTIGATIONS

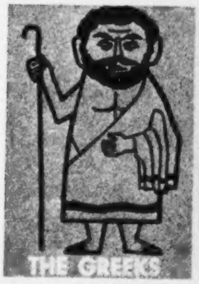
Much of our early information about the atmosphere was deduced from meager observations. Early Greeks deduced, from sightings of the auroral lights and observations of meteors, that an atmosphere existed up to altitudes of the order of fifty miles. Their scholars made an initial study of pneuma, as they called air, but did little beyond naming it.

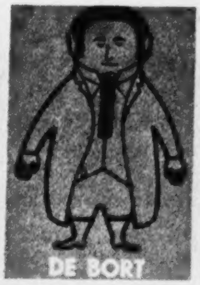
Men did not begin to accumulate and record much useful information about the atmosphere until the eighteenth century. In 1714, Edmund Halley of England, the foremost astronomer of his time, stated that the atmosphere extended upwards from the surface of the Earth for forty-five miles, and that the air within it became steadily colder and less dense toward the top, until it merged into outer space. Although this theory was intuitively appealing, it is incorrect quantitatively as will be shown shortly.

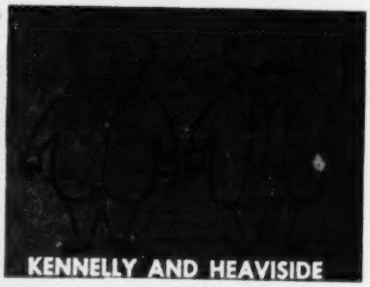
Later in the same century, a French chemist named Lavoisier became the first man to analyze the contents of the air.

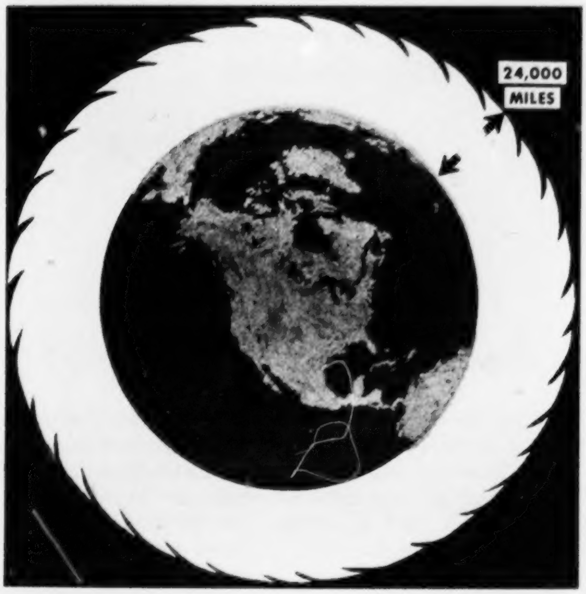
In 1898 another Frenchman named De Bort suggested the valuable concept of atmospheric layers surrounding the earth. He developed this idea as a result of balloon experiments.

Then, in 1902, came the studies of Arthur Kennelly of Harvard University, and Oliver Heaviside of England. They sought to explain Marconi's successful transmission of wireless signals across the Atlantic Ocean. Working completely independently of each other, they predicted that layers of charged particles, which would reflect radio waves, existed at heights well above the forty-five mile limit imposed by Halley. Recently more detailed studies have added to our knowledge of auroral lights, meteor trail analysis, and wave propagation including reflection of sound and electromagnetic energy from the layers of the upper atmosphere. Today we probe the air ocean directly with rockets and satellites which easily reach the outer limits of our atmosphere.









This so called outer limit is not definitely defined since the atmosphere shades gradually into the low density vacuum of interplanetary space. At this outer limit the atmosphere is so very thin that all the air particles within the space of ten cubic miles would hardly cover the surface of a pinhead. In this range (from about 350 miles upwards to a mechanical limit of between 20,000 to 27,000 miles) neutral molecules and atoms of air can escape into space as their centrifugal motion overcomes gravity.

Before we discuss the physical characteristics of the atmosphere further, let us define two different kinds of heating. Temperature is directly related to kinetic energy of motion. The heat energy which is imparted to a body by its collision with particles is kinetic. Heat which results from the absorption of energy directly from a radiating source (such as the Sun) is radiation heating. All the temperatures mentioned hereafter will be kinetic temperatures (due to particle motion) and will be expressed in degrees Fahrenheit, °F.

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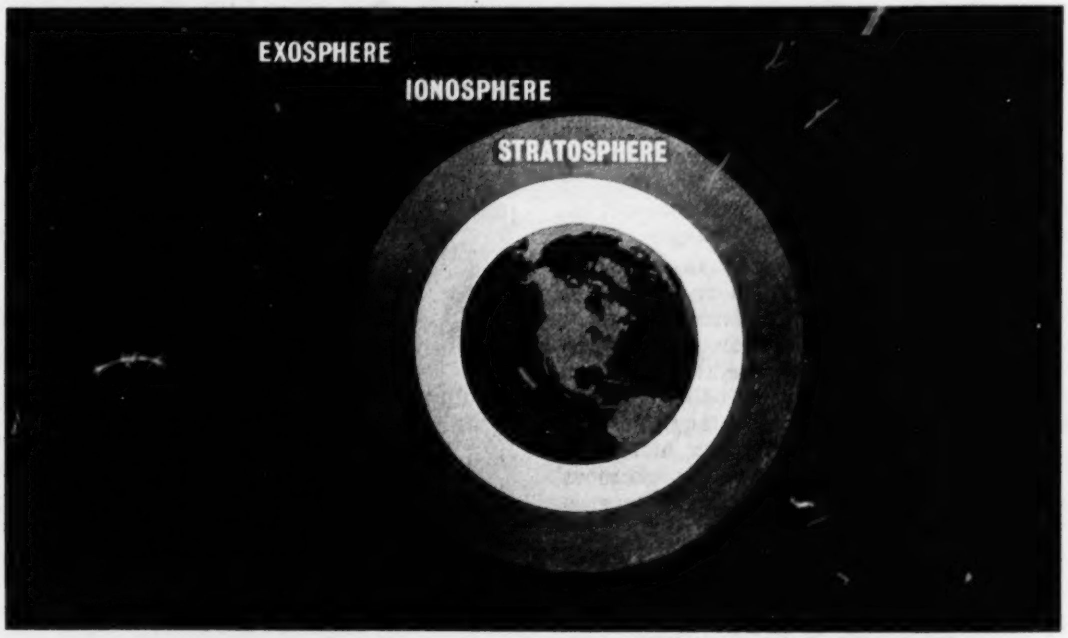
CURRENT KNOWLEDGE

In our present picture of the atmosphere, we recognize several layers which envelope the Earth as an onion skin. Although we might describe the atmosphere in any of its specialized characteristics (for example, by density or temperature) we shall discuss it primarily by altitude regions as four concentric shells labelled progressively troposphere, stratosphere, ionosphere, and exosphere.



Troposphere

The lowest shell is the familiar troposphere. It extends to heights of about five miles at the poles and ten miles at the Equator. The prefix "tropo" means turning over. Within this layer the air is constantly in motion due to wind currents that distribute heat and moisture around the Earth's surface. The troposphere is the area with which we are most familiar wherein weather and climatic changes are most noticeable.

Both temperature and pressure decrease with altitude within the troposphere. At heights of seven miles the barometric pressure is only one-fifth of that at sea level and the air is only three-tenths as dense. Temperature also decreases throughout the troposphere at the average lapse rate of 3.5°F for every 1,000 feet of ascent. The temperature, at the top of the troposphere, ranges from about -55°F in the middle latitudes at five miles altitude to -100°F at ten miles altitude above the equator. Between the troposphere and stratosphere lies a zone of transition which is often narrow and abrupt, yet sometimes at middle latitudes it consists of multiple layers. This transition zone is called the Tropopause and it varies in height with latitude and the season.

TROPOSPHERE

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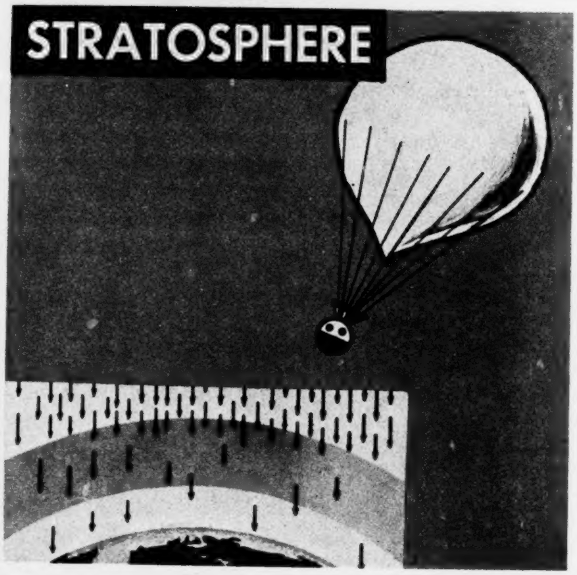
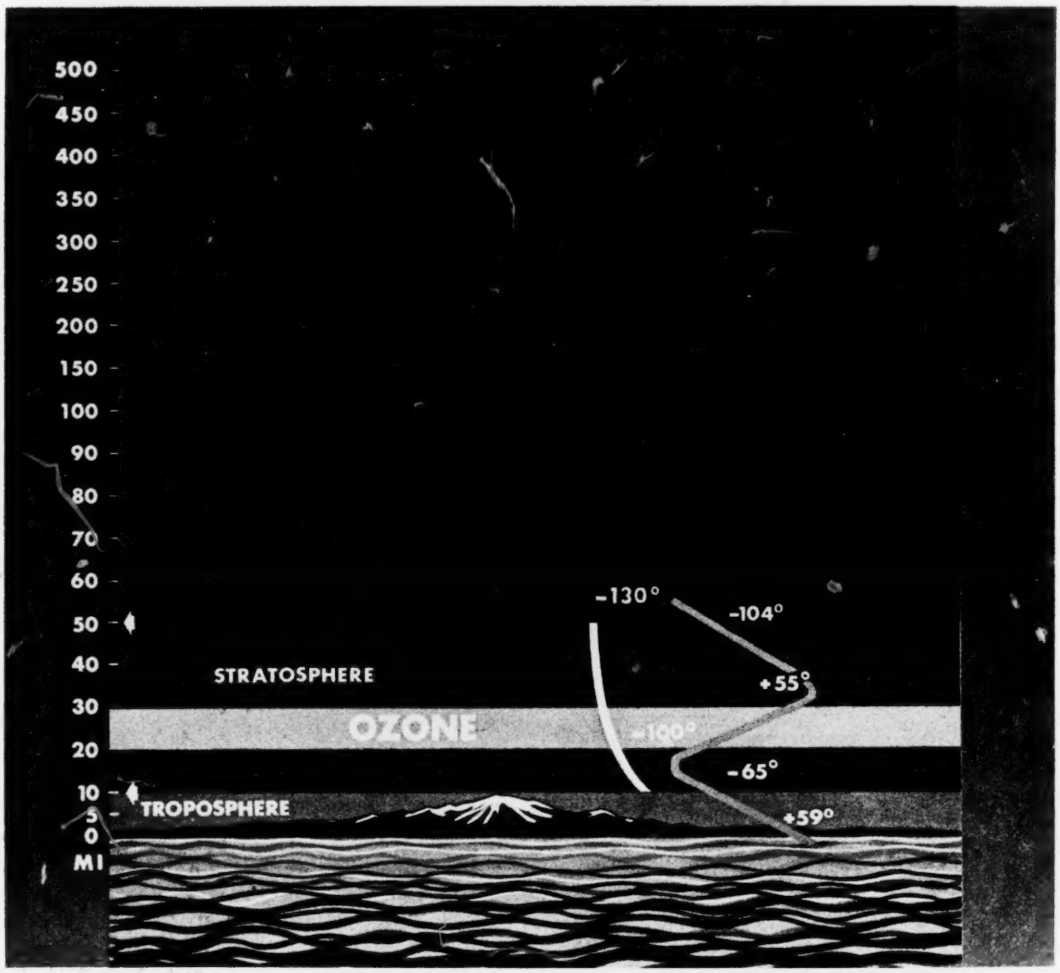
Stratosphere

When we leave the bottom floor of the air ocean and climb ten miles into the stratosphere we enter an unfamiliar realm. Hot and cold fronts as we experience them on the surface are left behind. There is little wind except seasonal jet streams, and water vapor is a quite negligible component. Although some physical continuity between the lower and upper air exists, and though the disturbances in one are often related to disturbances in the other, the stratosphere is separate in many ways. Although slightly affected by seasonal periods, the stratosphere, as we will consider it, ranges in altitude from ten to fifty miles.

In the lower level of the stratophere, from about twenty to thirty miles, there is a most important ingredient of our atmosphere, ozone. Ozone is an allotropic form of molecular oxygen formed by a photochemical reaction between sunlight and oxygen. A molecule of ozone consists of three atoms of oxygen instead of the two atoms found in the more common oxygen molecule. Ozone acts as a filtering agent to absorb most of the ultraviolet radiations with wave lengths greater than 2100 Angstroms (1 Angstrom = 10^{-8} cm). Most of the remaining dangerous ultraviolet rays are absorbed by the lower and more dense troposphere. The few rays that do penetrate to Earth contribute to healthy human life.

This ozone layer, which is so vital to the preservation of life, actually is not extensive. If the entire atmosphere were to be compressed to sea level pressure, the resulting depth of material would be nearly five miles thick. On this scale the ozone layer would be slightly less than one-twelfth (1/12) of an inch!



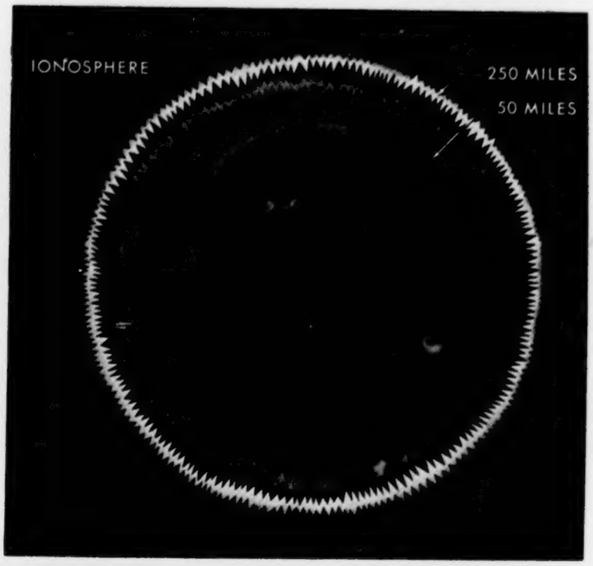


If we consider temperature changes throughout the stratosphere, we notice that at first the temperature (shown as the right curve in the figure) begins to increase with altitude, chiefly, because of the absorption of ultraviolet radiation by ozone. However, since ozone is located principally in the lower levels of the stratosphere, the temperature curve mounts but briefly, and then decreases again. The temperature rises from about -65°F at the bottom of the stratosphere to +55°F near thirty miles, and then decreases to -104°F at 50 miles. (Frequently this stratospheric region is subdivided for discussion into (1) a stratopause at about 19 miles where the temperature is about -100°F, (2) a mesophere for the range of altitudes between twenty and fifty miles where the temperature decreases, and (3) the mesopause where the temperature has its lowest value in the atmosphere, -130°F or less, at fifty-five miles).

Pressure (shown as the left curve in the figure) decreases continually until at fifty miles the absolute pressure is only 1/100,000 of the sea level pressure. The density is also 1/100,000 of the sea level density. Within these first fifty miles of altitude the composition of atmosphere is relatively uniform, and atmospheric density decreases by a factor of approximately ten for every ten miles increase in height. This atmospheric region of uniform composition is called the homosphere. Beyond the homosphere, commencing at about sixty miles, we enter the heterosphere where composition changes with altitude.

Ionosphere

Perhaps the most interesting of all atmospheric layers from the aspect of understanding its physical effects is the highly charged ionosphere. The ionosphere extends from 50 miles to almost 250 miles in altitude. (Frequently this region is also called the thermosphere because here the temperature rises rapidly with altitude.) It is really a buffer region in the atmosphere. On it falls an immense electromagnetic bombardment of light rays, ultraviolet and infrared radiations, radio waves and corpuscular streams from the sun and similar radiations from beyond our own solar system. These impacts produce a great variety of effects on the molecules and atoms of the upper air. For example, ultraviolet radiations frequently knock electrons from air molecules or break-up molecules into atoms leaving charged particles called ions. High energy cosmic rays, colliding with atoms of air, produce powerful secondary showers and cascades of electrons, mesons, and other "strange" nuclear particles.



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Many radical changes occur in the gases of the ionosphere. Nitrogen and oxygen appear as individual atoms instead of paired as molecules. Free electrons are produced leaving many atoms in the ionized state (ions). These electrons and charged ions interact to form great ionized layers. Definite correlations have been established between solar eruptions and the electron density of ionospheric layers. These strata are occasionally the scene of the electromagnetic storms that disrupt radio communications. The ionized layers are not constant in thickness, but swell in the sunlight in the daytime, and shrink at night. You have probably noticed that radio reception at certain frequencies is better at night than by day. The absence of sunlight causes ionized layers to develop less at night, to occur at higher altitudes, to create less static, and to lose less vibration energy to neutral air particles, thereby permitting more efficient bounce back of radio energy over larger distances than during daytime.

17

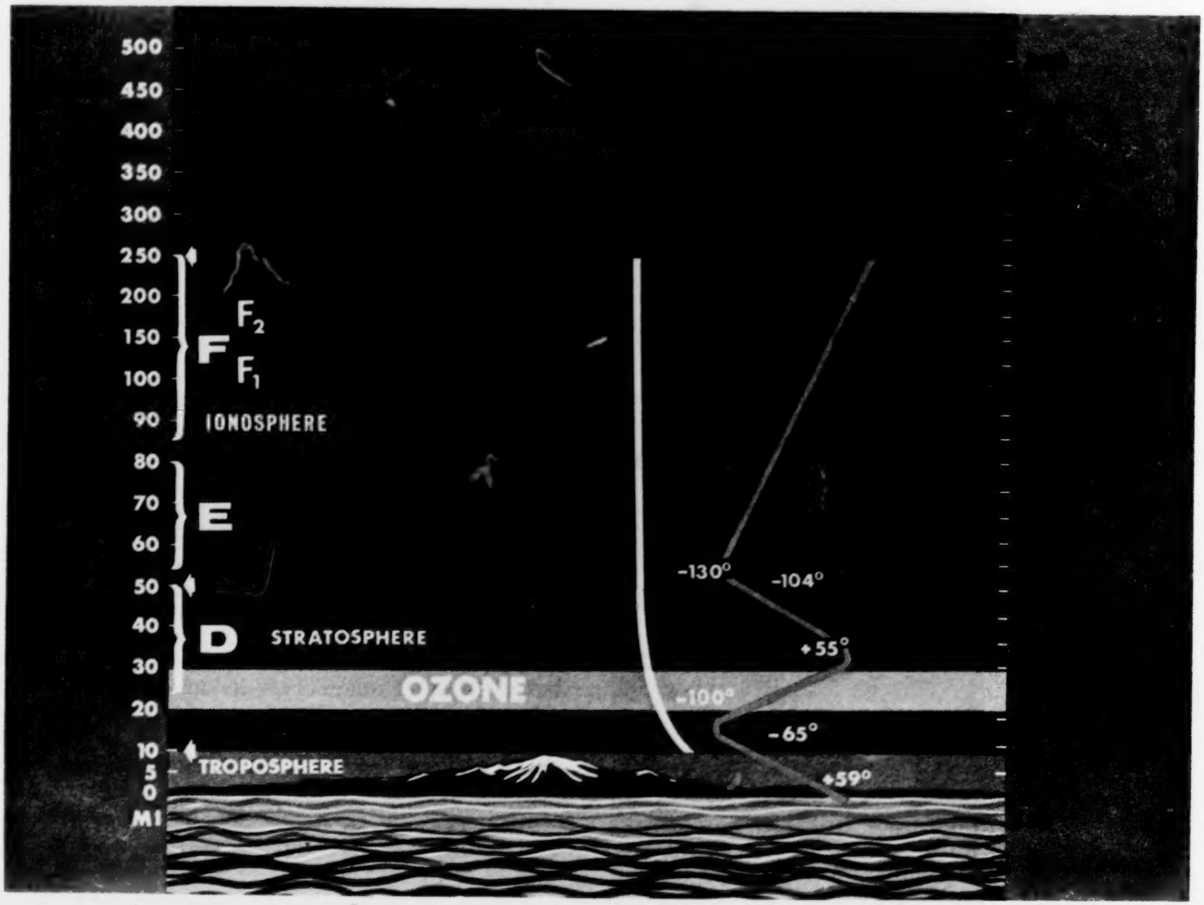
The ionosphere is usually subdivided into D, E, and F layers. These layers exhibit different responses to radio waves based upon the depth of penetration and the vibration frequency of the wave.

The D layer is the lowest in altitude. It dips into the upper stratosphere and lies between 25 and 50 miles, with its maximum ionization activity between 35 and 40 miles. This layer absorbs some of the energy re-radiated by the earth in the manner of a greenhouse.

Next is the E layer called either the Heaviside or the Kennelly-Heaviside layer after the two scientists who studied this region. It extends from 55 to 80 miles in altitude and its maximum ionization is between 70 and 80 miles. Sporadic-E effects are sometimes present in this layer, especially in summer. This erratic phenomenon interferes drastically with radio propagation. It is associated with a rapidly fluctuating increase in electron density frequently observed in daytime near the equator and at night near the poles.

Immediately above the E layer is the F layer which extends from 85 to 250 miles in altitude. The F layer is subdivided into the F1 and F2 layers. The maximum ionization for the F1 layer occurs from 135 to 145 miles. Within this F1 region an ionospheric turbulence, called the spread-F effect, causes scintillation or irregular fluctuations in radio signals. The F2 layer has maximum ionization from 190 to 230 miles.

The aforementioned layers of the ionosphere are referred in modern terminology as regions rather than layers because the so-called ionized layers, in which free electrons are the active vibrators, actually are broad maxima of electrons present in a highly charged ionosphere.



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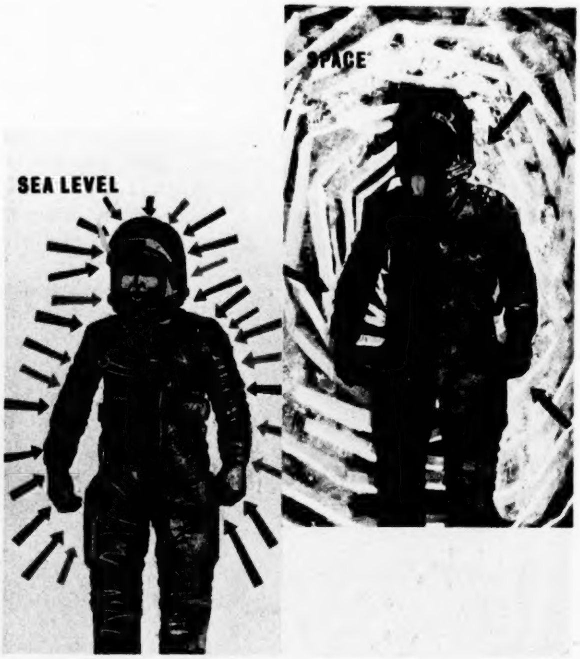
In the extremely tenuous gases of the ionosphere, the scattered atoms and other particles are heated primarily by the radiant energy of the sun. Temperatures in the ionosphere soar to 2000°F and higher in the upper regions based upon the kinetic energy of the particles. Yet at these heights, man would freeze at night. There is little reflected sunlight to keep him warm, and the air particles are so few and far apart that they will not keep him warm by contact. At the top of the ionosphere, only about fifty thousand billion (5 times 10 to the 13th power) particles would strike each square inch of a body every second. However, these impacts would convey only a small portion of the heat conveyed by the far greater number of air particles at sea level where a square inch is struck by ten quintillion billion (10 to the 27th power) particles each second.



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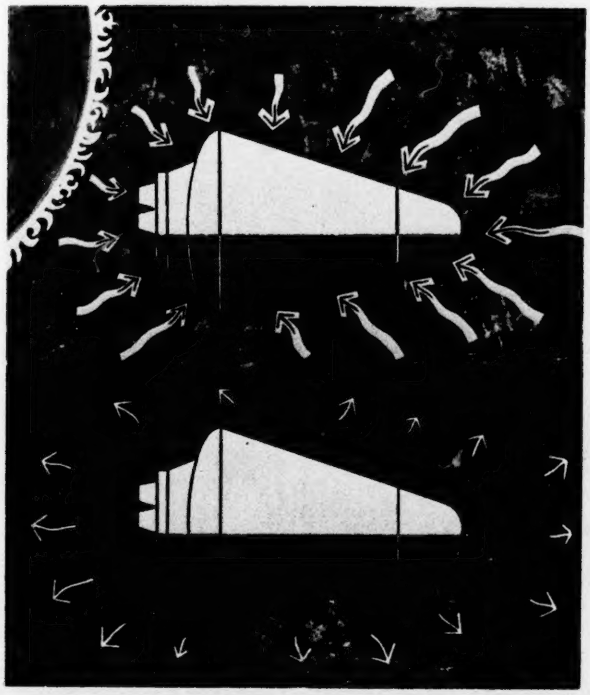
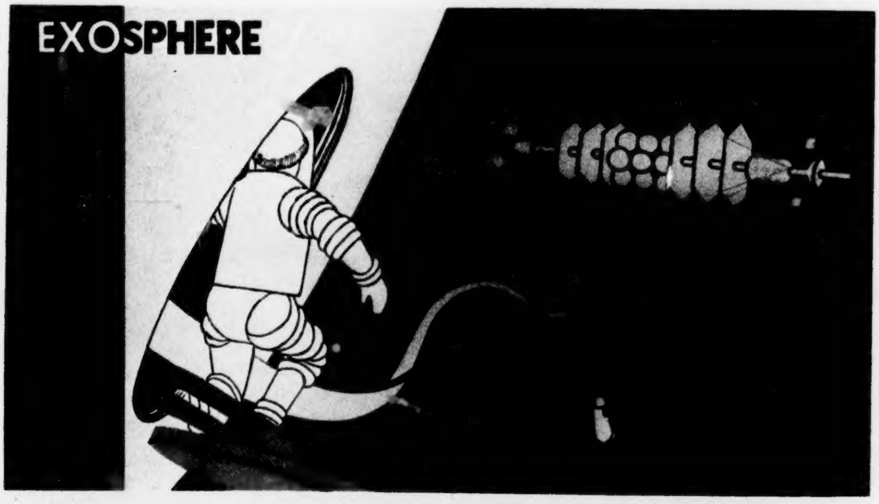


In the ionosphere, as in most of the stratosphere, and all of the higher exosphere, heat can be effectively transferred only by radiation because of the relatively low number of particles present. The particles do not reach an equilibrium temperature by collisions. Heating here depends primarily on the net exchange of absorbed radiation and emitted radiation. A spacecraft at these altitudes may be intensely heated while exposed to the sun. But as soon as the sun disappears, or the craft passes into the shadow of the earth, it loses heat through emission of energy radiated into space. There is no atmospheric blanket of sufficient consequence to reflect this heat lost by radiation. The ionospheric air is much too rare. This is easily demonstrated by the calculation that a GEMINI spacecraft in one complete orbit of the earth at an altitude of 150 miles will encounter only a total of one-third of an ounce of air. At sea level the spacecraft in one orbit would have encountered 22 million tons of air.



Exosphere

Somewhere between 250 and 500 miles in altitude the rare ionosphere merges with the even more tenuous exosphere. The chief difference between these two layers is that in the exosphere fast moving particles can escape from the earth. There is negligible probability that they will hit another particle and rebound back into the atmosphere. Any charged particles that are formed by the action of the Sun's rays are much too widely scattered to produce detectable charge layers as in the ionosphere. Instead, high in the exosphere there are charged zones of a very different nature: the geomagnetically trapped radiation in the Van Allen Radiation Belts.

Let us briefly consider the phenomenon of geomagnetically trapped radiation. Our Earth possesses magnetism. Magnetic fields, originating from magnetic materials and circulating currents within the earth, extend many thousands of miles beyond the surface to form a geomagnetic cavity in the solar system. This cavity can be defined as the total volume occupied by the magnetic field of the Earth to distinguish it from the interplanetary magnetic fields of other bodies, principally the Sun. This geomagnetic cavity, somewhat in the shape of a teardrop or comet's tail, reaches to about ten earth radii (40,000 miles) on the side closest to the sun commonly called the day side and many times further on the night side. Within the geomagnetic cavity charged particles are directly affected by the magnetic field of the earth. A companion term, magnetosphere, is also used to describe this region of the atmosphere above 500 miles wherein magnetic effects dominate the trajectories of charged particles.

Any charged particle in motion in a magnetic field is acted upon by a magnetic force directed at right angles to both the direction or particle motion and the direction of the magnetic field. In uniform magnetic fields, charged particles travel in helixes around the field lines. In nonuniform magnetic fields charged particles can be caused to reverse directions along the field lines and with certain field configurations be caused to oscillate or become trapped.

Geomagnetic trapping of charged particles occurs because the Earth's magnetic field is stronger near the surface than at higher altitudes. This is understandable if we remember the Earth possesses a dipole-like magnetic field similar to that of a thin bar magnet. The lines of force bunch together (field strength increases) as the lines try to enter or leave the poles of the Earth. This field configuration causes charged particles to move in tighter helixes as they travel to lower altitudes at higher latitudes where they enter greater magnetic fields. When the plane of rotation about the field lines becomes perpendicular to the field, the pitch angle of the helix becomes zero and the particles are reflected back (mirrored) along the field lines. When mirror points exist at both ends of the field lines (as happens in high North and South latitudes) then charged particles within a certain energy range will be geomagnetically trapped. With this brief review of electromagnetics let us examine the Van Allen Radiation Belts.

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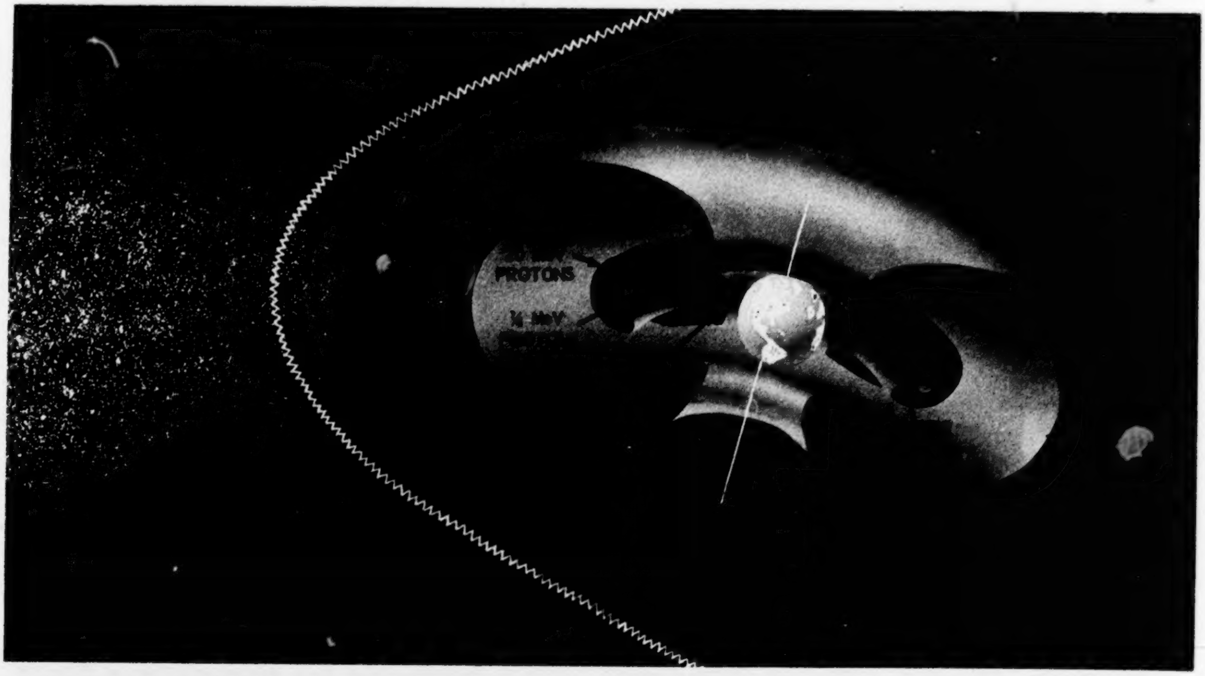
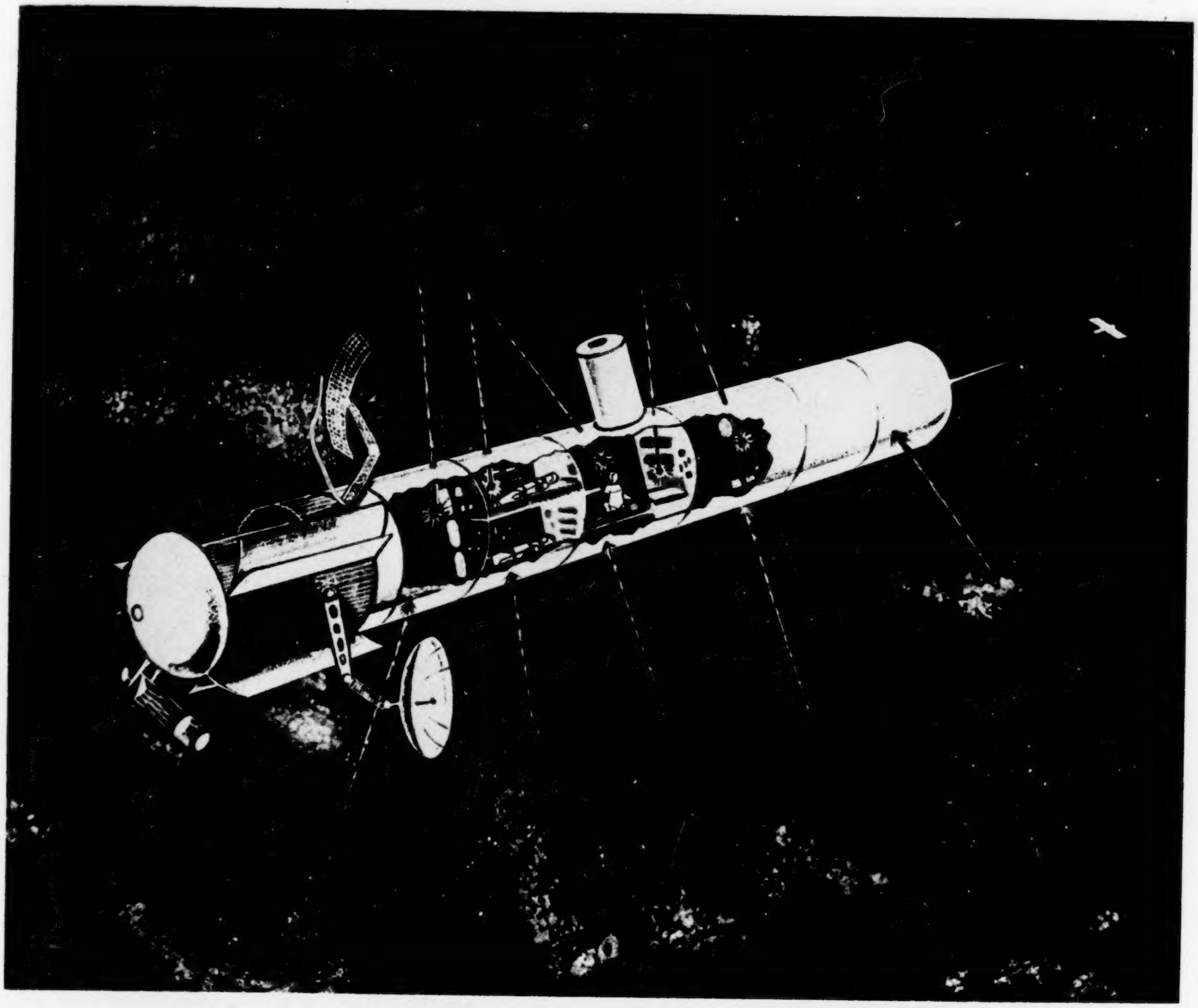


Views about the composition and energy of Van Allen Radiation have been modified significantly by information from recent space flights. Investigators now see a more coherent picture emerging. The magnetosphere on the day side interfaces with turbulant solar magnetic effects at about 40,000 miles from the center of the earth. Within this magnetosphere and extending to slightly greater distances on the night side protons and electrons are trapped in significant numbers in circumterrestial belts. However, the shape and boundaries of these radiation belts are not abrupt or distinct. Early investigators localized these belts into two zones: (1) An inner zone populated with high energy protons, and (2) An outer zone populated with energetic electrons. It now appears that there are even broader spatial regions with concentrations of both protons and electrons of definite characteristic energies.

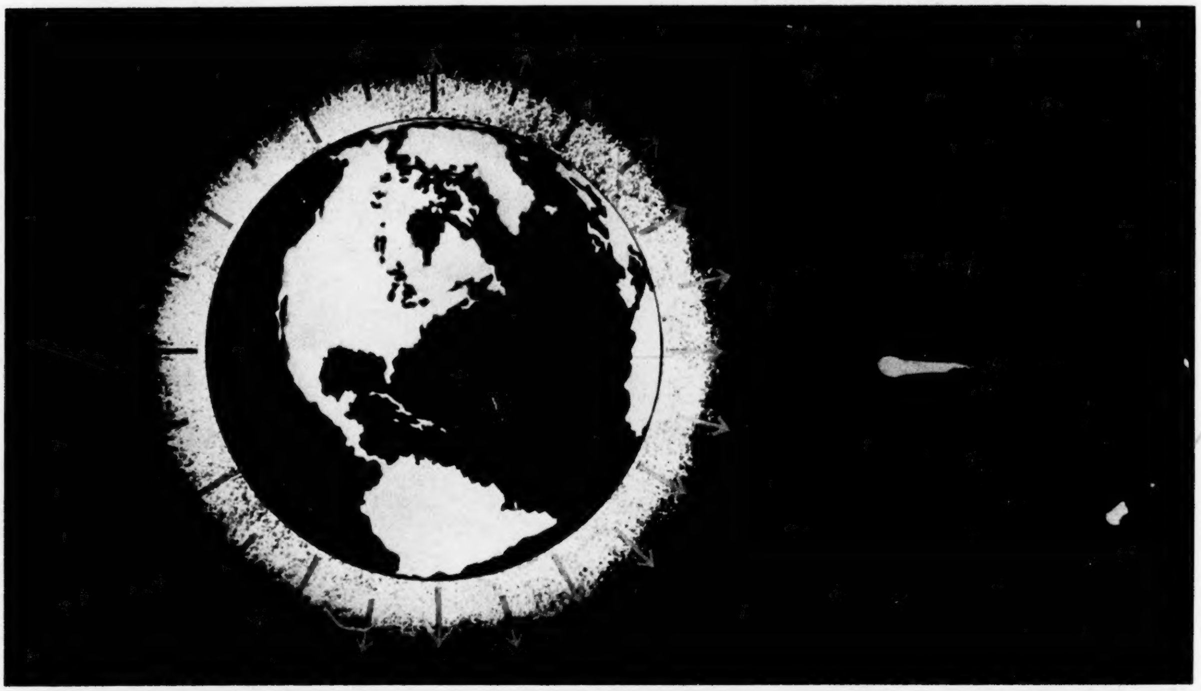
Let's locate these belts using geocentric coordinates. Starting at the center of the Earth and moving outward, there is a broad inner belt starting about 5,500 miles consisting of high energy protons with a spread of kinetic energies sometimes exceeding 100 million electron volts (MeV). At 11,000 miles there is a swarm of low energy protons (1/4 MeV), and immediately adjacent at 15,000 miles is a collection of 20 MeV protons and 2 MeV electrons. The outer belt extends from about 23,000 miles to the edge of the magnetosphere. It is principally filled with electrons with energies of about 10 KeV.

Scientists are actively engaged in determining the origin of the particles and the replenishment and loss mechanisms for these radiation belts. It has been established that protons from the Sun do affect the population density of the outermost zones, but the inner zone remains relatively stable despite frequent external perturbations. Some theorists hypothesize that the majority of the trapped protons of the inner zone came about by the decay of neutrons that have splashed back from collisions of cosmic rays with air molecules. This theory is called the neutron decay or albedo theory for populating the inner zone with protons. Some accepted loss mechanisms include absorption of charged particles by the atmosphere at higher latitudes and in the South Atlantic Radiation Anomolies. At present no unified theory answers all questions about the composition and history of the radiation zones. Furthermore, a temporary constraint or confusion factor to space investigations of the natural radiation zones are the remnants of artificial radiation zones created by charged debris from high altitude explosions of nuclear bombs. Continuing space research will add greatly to our knowledge of geomagnetically trapped radiation.



Although we have been talking in terms of great distances and very energetic particles, the trapped particles within the magnetosphere have an aggregate mass of less than one pound. However, within the radiation belts unshielded man would receive more exposure to radiation within one minute than the Atomic Energy Commission considers to be safe exposure within one week. Shielding to protect an astronaut from such a hazardous environment would require materials with the shielding equivalent of 100 pounds of lead per square foot. Not only is this Van Allen radiation directly dangerous to unshielded man but the problem is frequently compounded by energetic particles which, upon striking the hull of the spaceship, create intense secondary showers of radiation throughout the interior of the ship.

One initial plan for interplanetary flights had manned spacecraft departing Earth through the existing gaps of radiation over the polar regions. This would have entailed expensive propulsion costs to change orbital planes since we have not established launch sites at the poles. However, current plans for departing Earth include optimizing construction and placement of materials in the spacecraft to provide adequate shielding for astronauts to make rapid transits through the radiation belts without excessive weight of shielding materials.



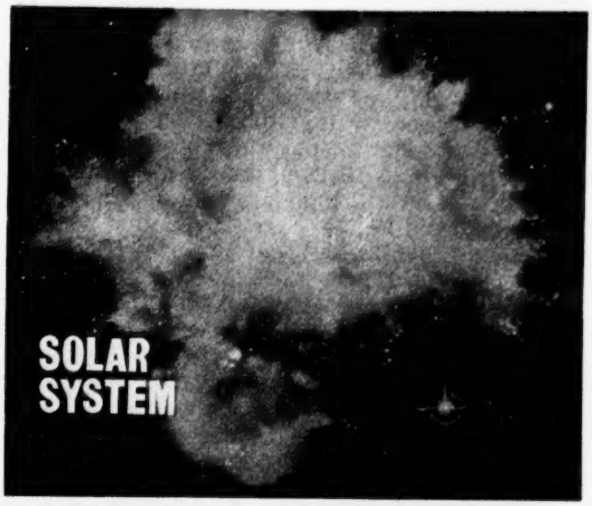
Geomagnetical trapped radiation is not, however, the only constituent of the exosphere. The belts themselves are merged in an extremely rare atmosphere composed almost wholly of charged atomic oxygen and nitrogen. Throughout the exosphere the individual gas particles are probably at temperatures well in excess of 2,000° F, especially during a sunspot maximum when they reach over 3000°F. These particles are present in decreasing amounts up to the mechanical height limit of 27,000 miles. At this altitude we have reached the surface of the air ocean surrounding Earth. Here stray particles from outer space fall into the atmosphere, and particles of air escape into space as they are thrown off tangentially at escape speeds of 25,000 miles per hour.

Even beyond the mechanical limit of our atmosphere we find much of interest. Electrons in the outer fringes of the Van Allen Belts drift around in the magnetosphere of Earth. A transition region extends from the edge of the magnetosphere to about 60,000 miles. This gateway to extraterrestial space is affected greatly by solar winds, flares, and storms. We will describe these phenomena when we consider next our star, the Sun.

CHAPTER 3

THE SOLAR SYSTEM

BACKGROUND



Through the centuries man has gazed at the Sun, the Moon and the stars and tried to understand the universe around him. This curiosity has led to detailed observations, theories, and now to planned investigations of our solar system. Such activities are loosely grouped under the field of astronomy, the oldest of all sciences. Recorded evidence of a lunar eclipse was made by the Chinese in 1136 B.C. While the Chinese, Babylonians, Egyptians, and others have made many contributions to our knowledge of the universe, it was the Greeks who developed astronomy to a level unsurpassed until the sixteenth century. Recall that it was one of the earliest Greek astronomers, Pythagoras, who probably first realized that the Earth was spherical (even if it was erroneously believed to be the center of the universe); Philolaus, who introduced the concept that the Earth is in motion; Aristotle, who first wrote clear and correct explanations of the phases of the Moon and of eclipses; Aristarchus, who devised a most ingenious method to find the relative distances from the Earth to the Sun and Moon; Hipparchus, who invented a geometrical representation involving eccentrics and epicycles, that very precisely described the motions of the Sun and Moon; and Ptolemy, who compiled a series of thirteen volumes on astronomy known as the "Almagest".

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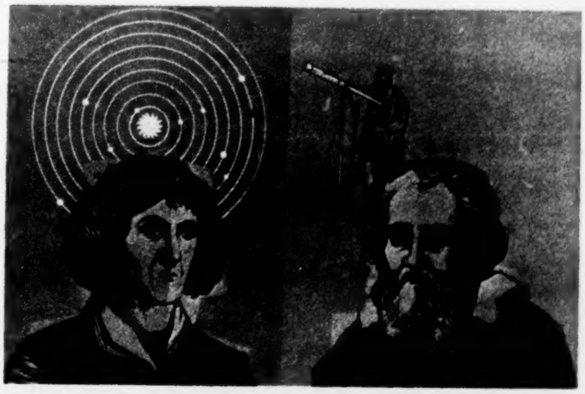
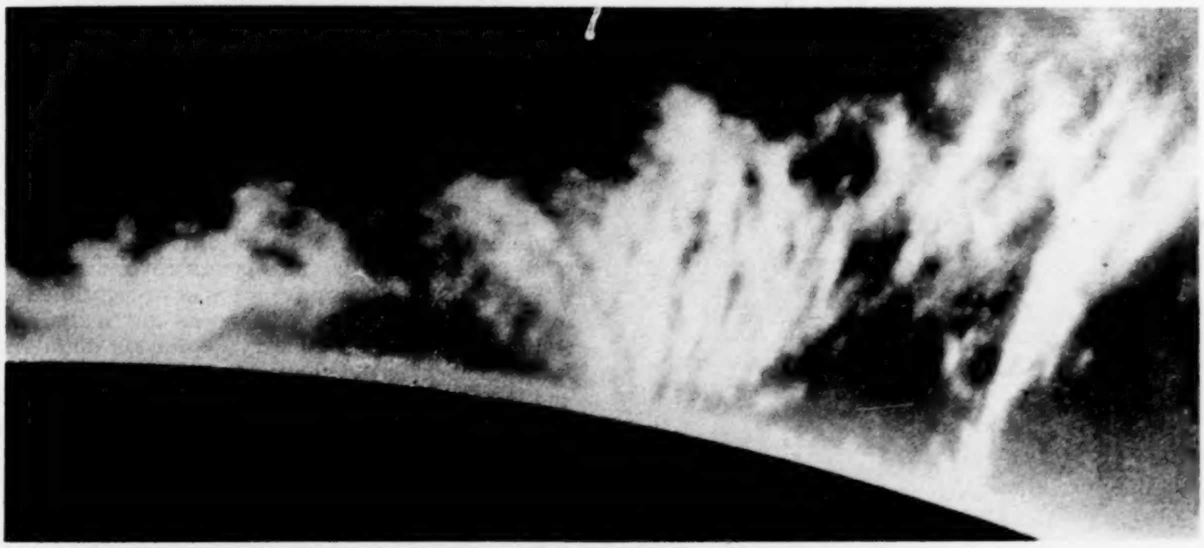


The concept that the Earth occupied the center of the universe, however, remained unchanged until 1530. It was at that time that Copernicus envisioned a solar system in which the Sun occupied the center with the planets revolving about it. This revolutionary theory was brought closer to acceptance by the telescopes of Brahe and Galileo. In the 17th Century Kepler set down the laws concerning the orbital travels of the planets and Newton formulated his laws of gravity and motion. Using these newly developed laws and scientific instruments, man brought not only the Sun and planets into closer view but developed a consistent theory of the solar system for our heritage.

SUN

Our solar system is composed of a star, the Sun, with a retinue of nine planets orbiting it at varying distances. Referred to as a third generation medium-sized star composed of luminous gas, the Sun constitutes 99.86% of the matter in our entire solar system. The Sun has a diameter of 865,000 miles (about 109 times that of Earth), and weighs 6.6 x 10^{21} tons (approximately one million times that of Earth). The Sun's gravitational attraction is such that a 100 pound object upon the Earth's surface would weigh about 2,700 pounds on the Sun. It is commonly called an old star (4-7 billion years' in age), yet is has not settled down to a uniform rotation rate. Rotation at its equator takes 24 days; at the poles it takes 34 days. The Sun's energy output is derived from thermonuclear reactions deep in its interior, where temperatures are calculated to be near 20 million degrees Fahrenheit. While the apparent surface temperatures average 11,000 °F, the corona attains temperatures near two million degrees. The magnetic poles of the Sun periodically change polarity as also happens occasionally with the intriquing spots which travel across its surface. These spots apparently portend significant physical reactions occuring on the Sun. Enormous arches of extra bright gas are often seen high in the Sun's atmosphere above the exposed poles of a pair of sun spots. Sometimes these arches reach to a height of 30,000 miles and bridge a span of more than 125,000 miles. Prominences that have quietly arched across thousands of miles for days on end have been seen to abruptly explode, propelling atoms out into space at speeds greater than escape velocity from the Sun (387 miles per second). Other magnetic discharges cause tons of fiery hydrogen to shoot up 100,000 miles or more above the Sun's surface. The greatest of all such spouts of ionized gas or plasma are the solar flares. These recurring phenomena may affect our manned space flights since they explode extreme distances into space, some as far as 500,000 miles.



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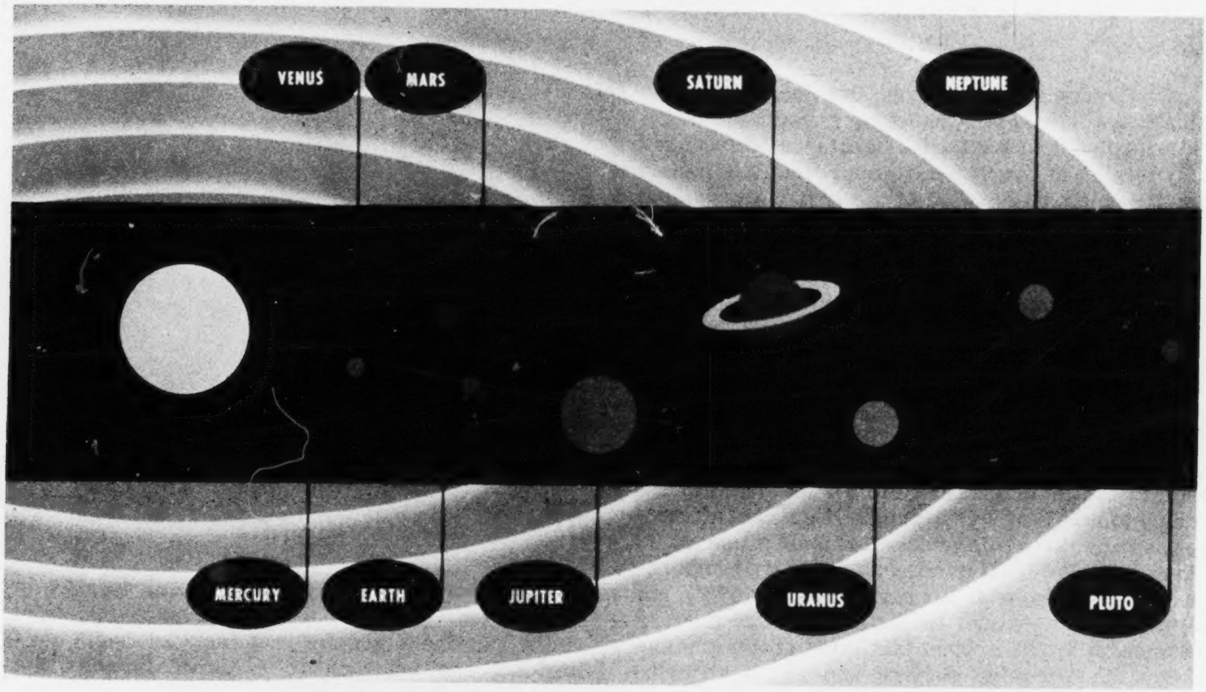

PLANETS

The planets orbit the Sun in the same direction and generally in the same plane. The usual reference to which the orbital planes of the planets are referred is the plane of the Earth's orbit about the Sun, called the plane of the ecliptic. Each planet's heliocentric path is an ellipse which varies in most cases only slightly from a circle.

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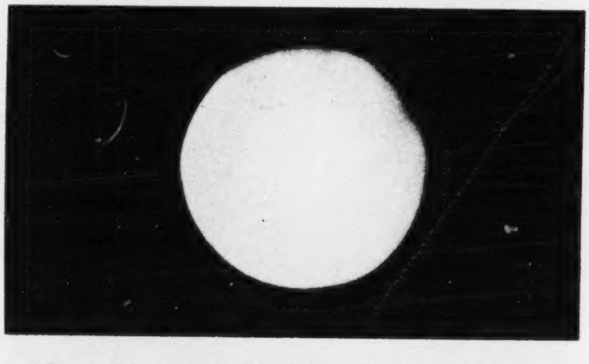
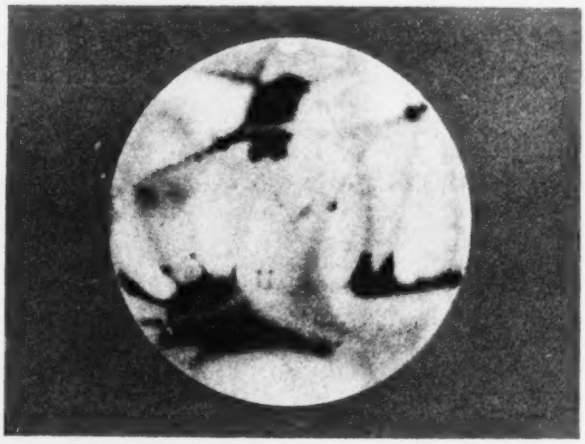
MERCURY



Traveling outward from the Sun to some 36 million miles, we first locate Mercury, an inferior planet named for the speedy messenger in Greek mythology. It is commonly known as the morning or evening star. It has the shortest period of revolution about the Sun (88 Earth days), and its mean orbital speed is nearly 30 miles per second. One of the brightest objects in the sky, Mercury is the least massive planet in the solar system and the smallest, having a diameter of only 3005 miles. Measurements indicate that the lighted side of Mercury has a temperature of about 610°K or (640°F), which is hot enough to melt tin and lead. Because of this high-surface temperature and the low velocity required by atoms to escape, Mercury should contain only a limited atmosphere. This is confirmed by its low back reflection (albedo), as evidenced by the fact that it reflects only 6 percent of the light incident upon it (less than any other planet). It probably possesses terrain features very similar to the Moon, and possibly has a shorter rotation than revolutionary rate causing days and nights.

VENUS

Continuing outward from the Sun, the second planet we encounter is Venus. Since it is the closest planet to Earth, its brilliance is exceeded only by that of the Sun and Moon. Venus is named for the ancient goddess of love and beauty, and is sometimes called the sister planet of Earth. It is most like the Earth in mass and size with a diameter of 7700 miles. Its orbit is the most nearly circular of the planets, having an eccentricity of only 0.007. Radar experiments indicate that the planet may be rotating on its axis in a direction opposite (retrograde) from that of the Earth and that its rotation rate is perhaps once per every 250 Earth days. This slow rotating rate accounts for the extremely low extent and intensity of its magnetic field as indicated by the magnetometer of the Mariner II spacecraft as it passed by at a distance of 21,648 miles on 14 December 1962. Mariner found that the temperature of Venus was approximately 800° F, and detected no openings in the dense cloud mass of condensed hydrocarbons that start about 45 miles above the Venusian surface and reach altitudes as high as 60 miles. Probes in late 1967 confirmed the hot surface (>500°F) and weak magnetic fields.



EARTH

Next we have one of the smaller planets in the system, Earth. As we have discussed most of the pertinent geophysical facts of Earth earlier we can pass on to a consideration of its natural satellite, the Moon.

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MOON

Of over 30 moons in the solar system, the one we see with the naked eye gets the most attention. Earth's own natural satellite is but a step away when compared to the distances to the planets.

The moon is about one-fourth the Earth's diameter, but it is not as dense. The Moon is generally thought of as being about 239,000 miles away. But this is an average distance, as it actually varies from about 226,000 miles at closest perigee to 252,000 miles at furthest apogee. Furthermore, astronomical distances are measured from body center to body center so by deducting about 5,000 miles for the combined radii of the Earth and the Moon, we can reduce the separation at the Moon's closest point of approach to some 222,000 miles.

The Moon circles the Earth every 27-1/3 days. This coincides with its rotation about its own axis, which accounts for the same side always being presented to the Earth. Due to effects known as librations, the Moon appears to rock slightly on its axis in all directions.

As a result of these librations somewhat more than half of its surface has been observed from Earth. To be exact, 41% is always observable from Earth and 41% cannot be observed. The remaining 18% may be observed, depending upon the time of observation, and the observer's position on the Earth. The advent of satellites that orbit the Moon is producing valuable photographs and information on the backside of the Moon not observable from Earth. The Moon is devoid of any atmosphere, thus, there is no gradual temperature gradient from hot to cold. An object partially in the sunlight and partially in the shade would be subjected to extreme heat and cold simultaneously. From its reflecting power we are able to compute the Moon's surface temperature. It ranges from about 260°F at noon on the Moon, to about -240°F at midnight. We will discuss the Moon further when we consider Astrodynamics.

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MARS

Beyond Earth lies Mars, named after the god of war but often called the "red" planet. While Mars has a small diameter of 4200 miles, it possesses two moons: Phobos and Deimos.

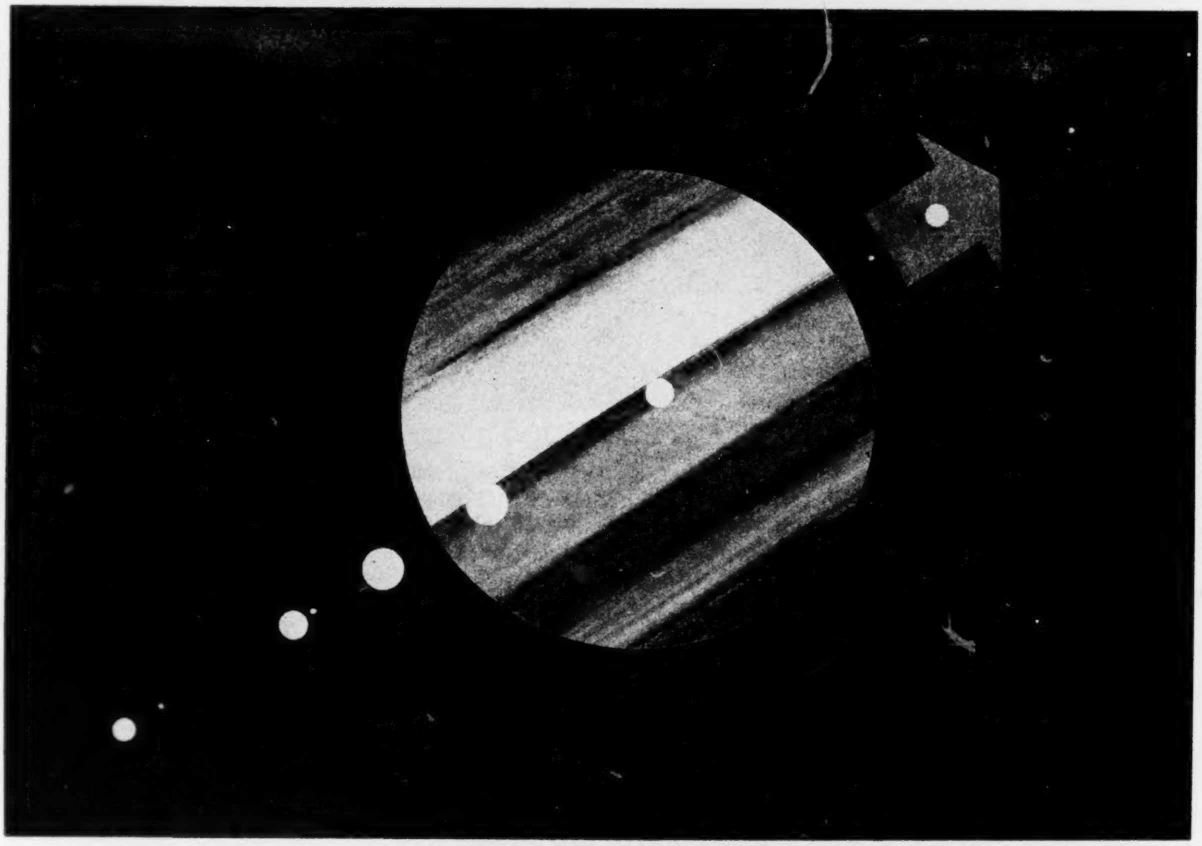
Additional information and photographs were obtained when NASA's Mariner IV flew within 7400 miles of Mars on 14 July 1965. During this flyby period, no significant changes in magnetic field or radiation intensity were observed from the levels prevailing in interplanetary space. It is probable that Mars contains no hot liquid metal interior. This would explain the absence of a magnetic field, which is believed to be associated with the motion of magnetic fluids in a planet's core. The photographs of Mars show a surface pitted with craters with a type of frost around the Martian-polar regions. There are no readily apparent straight-line "canals", and no mountain chains or great valleys. An extremely thin atmosphere does exist. The surface pressure of this Martian atmosphere is lower than ten millibars as compared to the approximately 1000 millibars of actual sea-level pressure on Earth. It possesses an ionosphere capable of reflecting radio frequencies as high as 3000 kiloHertz. Radio communication between points on its surface should be possible if exploration is conducted.

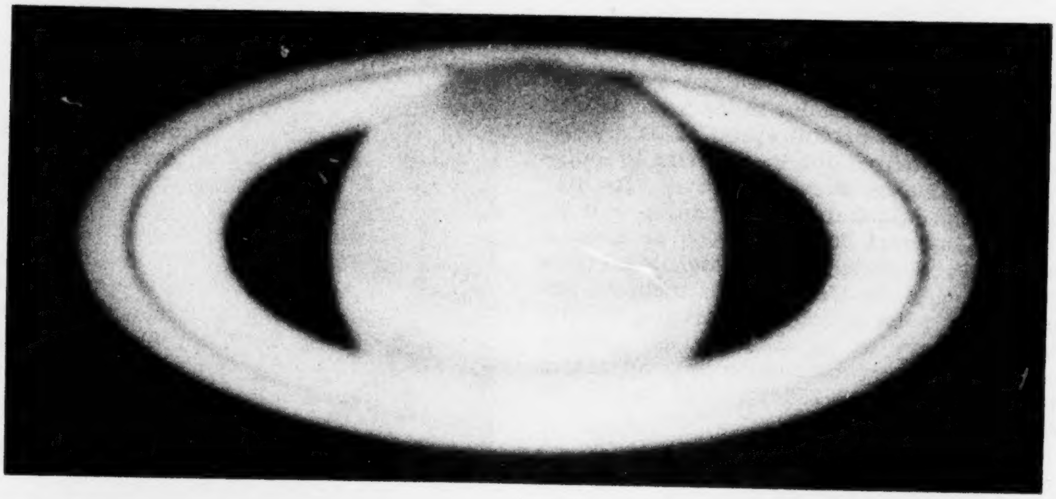
ASTEROIDS

Between the orbits of Mars and Jupiter there are concentrated the multitude of small bodies referred to as minor planets or the asteroid belt. Their orbits are highly irregular, generally falling between Mars and Jupiter, but with some such as Icarus, passing closer to the Sun than does Mercury, (in 1968 as close as 4 million miles to Earth). Apollo and Adonis come within the orbits of Earth and Venus. The largest, Ceres, has a diameter of some 400 miles. Because of their small size and rocky terrain they are referred to as orbiting mountains.

JUPITER

Beyond the asteroids is the orbit of Jupiter, the colossus of the solar system, more massive than all the other planets combined. It orbits some 484 million miles from the Sun. Although it never comes closer to Earth than 367 million miles it usually outshines everything in our night sky except the Moon and Venus. Named for the king of the Greek and Roman gods, Jupiter has a diameter of 87,000 miles, and its mass is some 318 times that of Earth. Violent storms exist in its hostile atmosphere and even today we know far too little about this giant. Jupiter radiates more heat than normally expected from reflected sunlight alone, and its Great Red Spot, sometimes measuring 30,000 miles across, remains a mystery. Jupiter's rapid rotation, averaging one rotation every 9 hours 35 minutes, has caused it to become noticeably oblate. Since its equator is inclined at only three degrees to its orbit plane, the planet has no appreciable seasons. Jupiter's surface gravity is 2.64 times greater than on Earth, and it can easily retain all kinds of gases in its atmosphere, especially hydrogen and helium. Jupiter has twelve moons and Ganymede, one of these satellites, possesses a noticeable atmosphere.





SATURN

Named for the ancient god of time, or for the Titan god of seed-sowing, the beautiful ringed-planet Saturn is the solar system's second largest planet. Of its nine satellite moons, only Phoebe moves in retrograde motion and only Titan seems to have an atmosphere. In addition to its known satellites, Saturn has a most impressive ring system. First observed by Galileo, the rings of Saturn are actually three distinct bands made up of billions of minute solid particles. These bands are some ten miles in width and exist outward from 7000 miles to 171,000 miles above the planet's surface. Saturn has a mean diameter just under 72,000 miles and an average density of only 0.71 times that of water, the lowest of any planet in the solar system. It is the most oblate of all the planets and the mean rotation period is approximately 10 hours and 38 minutes. Like Jupiter, the atmosphere of Saturn is believed to consist principally of hydrogen and helium.

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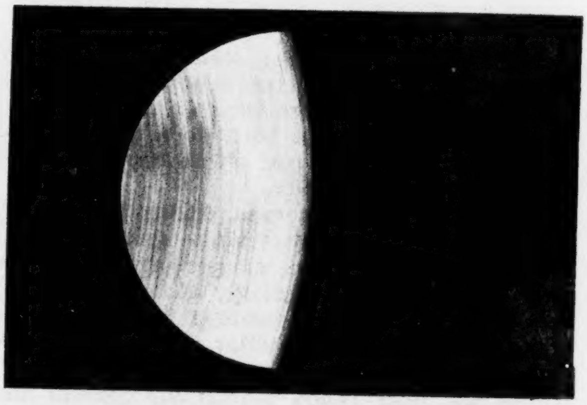
URANUS

Named for the Greek god of the heavens, this planet is most difficult to see without a telescope. Uranus, located a median of 1783 million miles from the Sun, has a diameter of some 29,500 miles. Uranus appears to be composed of methane, ammonia, and hydrogen. These gases exist primarily in a solid-state due to the extreme cold (-300 °F). Its direction of orbital revolution is normal (that is, from west to east), and it is accompanied by five satellites. None of the satellites are known to be much over 1000 miles in diameter. Since it is far from the Sun, its orbital speed is low (4 1/2 mi/sec). The length of time taken for one revolution around the Sun is 84 Earth years. A unique feature about Uranus is that its axis of rotation lies almost in the plane of its orbit, thus during some parts of its revolution it is so oriented that we look almost directly at one or the other of its poles. Uranus appears greenish when seen through the telescope, probably because of its atmospheric methane.



NEPTUNE

Neptune, named for the ancient god of the sea, is located 2,700 million miles from the Sun and travels with an orbital speed of only about 3 mi/sec. It requires 165 Earth years to complete one revolution around the Sun! Its diameter is approximately 25,800 miles and it, like Uranus, appears in a telescope as a small greenish disk. Neptune has two satellites: Triton and Neried. As in Uranus both methane and hydrogen have been detected spectrographically. Ammonia appears to be absent in the gaseous state, as would be expected since the temperature of Neptune is near (-350°F), well below the freezing point of methane.

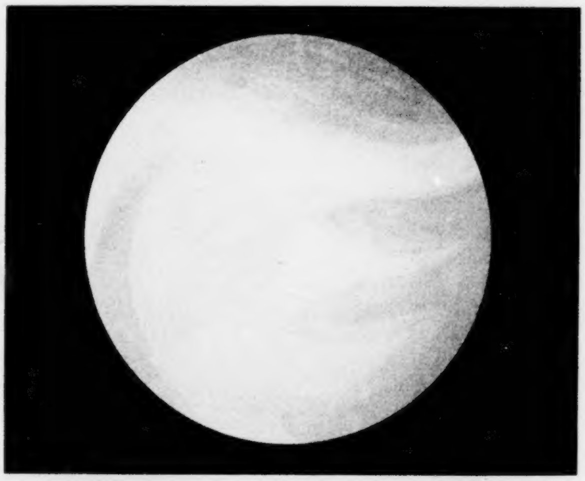
PLUTO

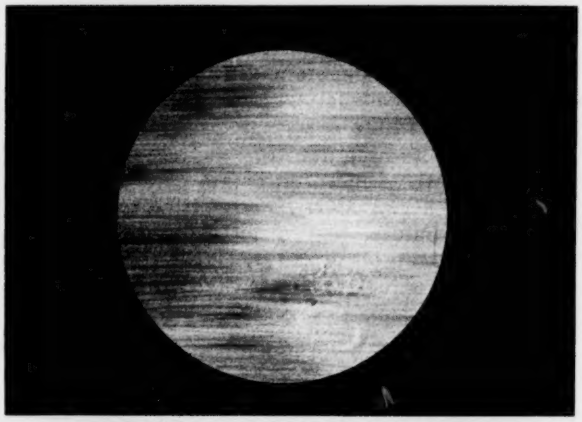
At 3,671 million miles from the Sun, we find the second smallest of the planets, Pluto. Named for the Greek god of the underworld, Pluto is much more difficult to see than Neptune. This small planet has a diameter of 3,600 miles and possesses no satellites. It taken 248 years to revolve around the Sun as it leisurely pokes along at a mean velocity of only 2.9 mi/sec. In all likelihood, Pluto has no atmosphere. This planet is so cold (below -350°F), that even its gases, if it has any, must be frozen solid.

COMETS

Comets are the most plentiful individuals in our solar system, numbering about 100 billion. They are interesting primarily because they are the travelers of the solar system. They wander throughout its far reaches (out of the plane of the ecliptic) and return back to our Sun. In general, comets are believed to be composed of frozen gases that boil off luminous tails as they streak through space.

What we have observed during this review of man's heritage in our solar system is only a small representative sample of the wonders that abound in the seemingly endless universe. We have become quite familiar with our immediate neighborhood, the solar system. With increasing distance our knowledge fades. Eventually we must reach beyond our current dim boundary (the utmost limits of our present telescopes and spacecraft) and move into our expanding universe. The next chapter will survey the chart of such a voyage into this "ocean of stars".





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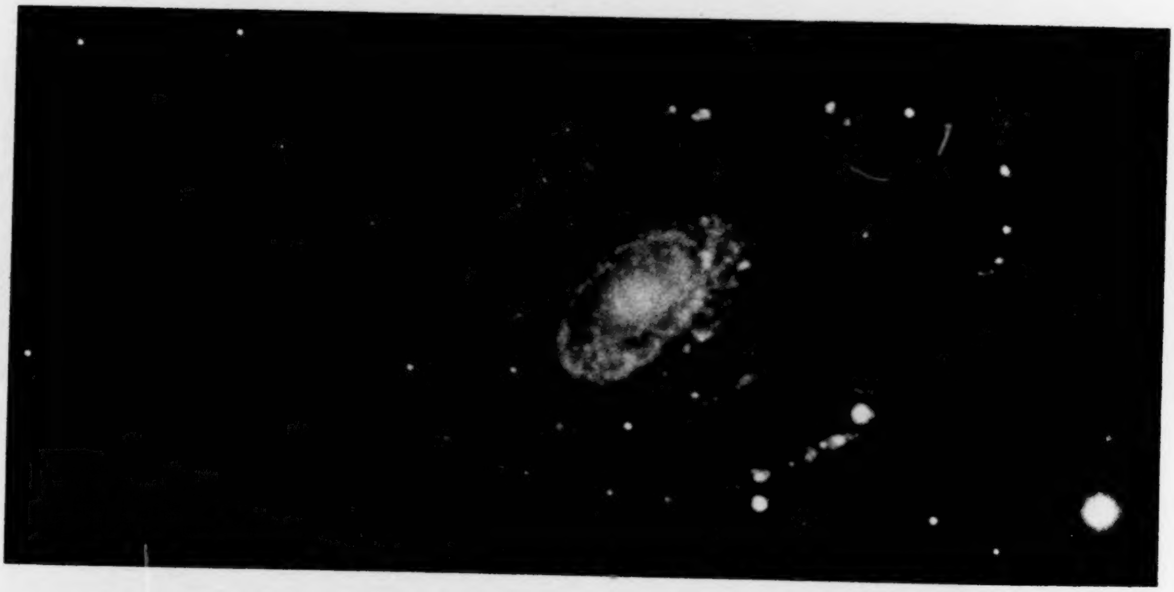
CHAPTER 4

THE UNIVERSE



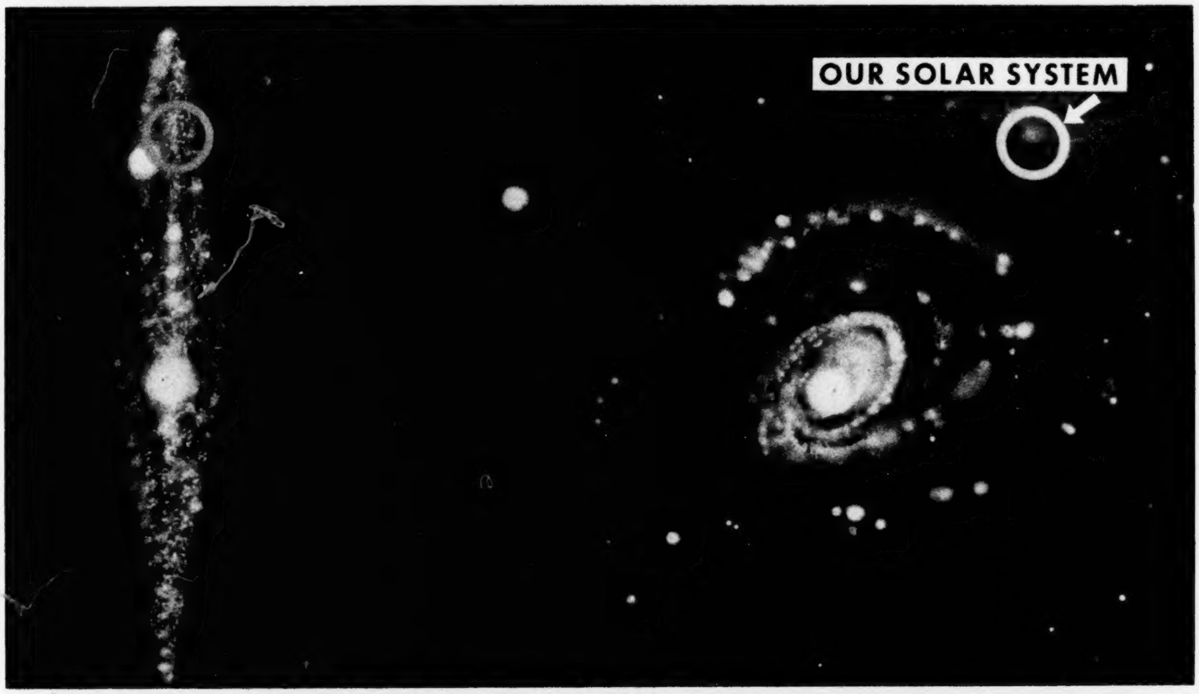
In the last two chapters we discussed both the Earth's atmosphere and the solar system of which Earth is a part. We now continue the investigation of our physical surroundings by considering one of the most awe-inspiring concepts within the imagination of man, the Universe.

Astronomy, defined by Webster as "the science of the stars and other heavenly bodies," is one of the oldest of all sciences, having its start with the Chinese around 1000 B.C. However, it was not until the early 16th century that Copernicus envisioned the solar system as we know it today.

The invention of Galileo's telescope in the 16th century enabled man to expand his studies of the heavens manyfold. This tool enabled Kepler to detail the movements of planets around the Sun. Newton subsequently utilized Kepler's observations in the development of his laws of gravity and motion.

Many years passed before people accepted the fact that the Earth was not the center of the universe. However, it was finally realized that our planet Earth together with the rest of the solar system are but mere specks in the infinite sea of the universe.

One might wonder why it has taken several thousand years of observation to determine such fundamental relationships. The problem has been and still is, one of perspective. It is impossible to find a position in space from which to view all the parts that comprise the universe. Instead we have been forced to extrapolate from the limited observations obtainable here on Earth. For example, it is impossible for us to view our own galaxy as a whole. However, by observing other galaxies and comparing the observable parts of our own galaxy with them, we are able to generate a fairly accurate picture. Proceeding in this manner, man has been able to learn a great deal about his environment.



Our star, the Sun, is one of about 100 billion stars rotating in the form of a spiral about the center of our galaxy, the "milky way". This spiral is roughly pancake in shape, having a diameter of 100,000 light-years and a thickness of 10,000 light-years. (One light-year is the distance that light, moving at 186,000 miles per second, travels in one year: nearly 6 billion miles). We are located at a position about 27,000 light-years from the galactic center, rotating about it at a tangential velocity of 200 miles per second. The period of rotation is around 200 million years.

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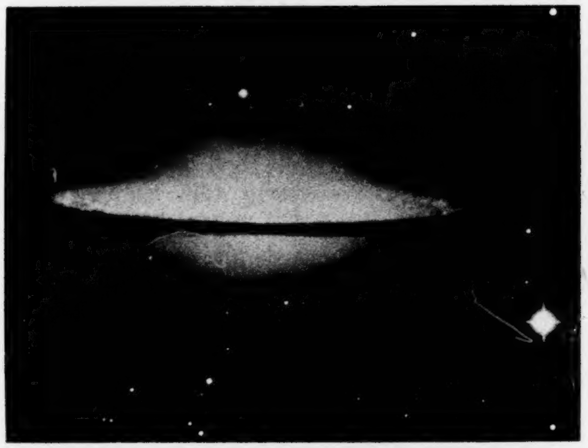
Most of the other stars in space are also formed in galaxies. These galaxies take the shape of spirals, such as our own, ellipses, and some irregular shapes. The galaxy nearest to us is one of the Magellanic clouds at 200,000 light-years.

The largest body of associated stars in the universe consists of a number of galaxies (between 10 and 10,000). This body is called a local group. The local group of which we are a member consists of 13 galaxies in addition to our own. The distance between local groups is on the order of 100 million light-years. There seems to be little association among the member galaxies in a local group other than the fact that they move together through space. The weakness of this association is indicated by the distance between galaxies, roughly a million light-years.



THE BIG BANG

A study of the movements of other groups in relation to our own indicates that they are all moving away from us at speeds directly proportional to their distances. Thus, there would seem to be a distance at which matter is moving faster than the speed of light, in contradiction to our present physical laws. We are unable, at this time, to view objects at this distance and so cannot confirm this extrapolation, however, many scientists seriously doubt its validity.

Before looking further into space one must understand the fundamental limit placed on our observations by the finite speed of light. Much of the information from objects in space is transmitted by electromagnetic waves which travel impressively fast. Yet even at the speed of light it would take 4.2 years to reach the nearest star, 200,000 years to reach the nearest galaxy, 100 million years to reach the nearest local group, and 2 billion years to reach the limit of our telescopes.

Thus, when we look at objects in space we are seeing them not as they are now, but as they were many years ago. When one tries to look at the universe as a whole, he is faced with the problem of being unable to view all its parts simultaneously. The difference in time between the nearest observable star and the furthermost is 2 billion years.

With these thoughts in mind let us now examine the theories and speculations of cosmologists, who deal with the nature and principles of the universe, and of the cosmogonists who deal with its creation.

The "Big Bang" theory was first proposed in 1927 by Belgian astronomer Georges Lemaitre. Recently, this theory has been supported by many scientists including George Gamow who has written a book, The Creation of the Universe. According to Gamow, all matter in the universe was originally concentrated into an incredibly dense glob. The dimensions of this glob were as infinite as space itself. Where was the center ? One must accept that an infinity of space or matter has no center.

According to this theory, creation began 5 billion years ago with a great explosion which sent dust and gas hurtling through space in all directions. The stars eventually were formed from this expanding matter, and Gamow believes this expanding motion will never cease.

While certain scientists believe this theory, many support the proposal of Bondi, Gold, and Hoyle developed at Cambridge in 1948. The Steady State Theory, as it has been named, suggests that the universe has always been expanding, without the moment of creation that the "Big Bang" theory suggests. Hoyle says, "every cluster of galaxies, every star, every atom had a beginning, but not the universe itself."

Recent observations have supported Gamow's theory and, as a result, many scientists, including Hoyle, have moved away from the Steady State idea. Many other models of the universe have been proposed. Francis Bacon has said, "many hypotheses with regard to the heavens can be formed differing in themselves, and yet sufficiently according with the phenomena." This is quite true today, but it is expected that bigger telescopes and observation posts on the Moon and in satellites will provide the information necessary to confirm the correct hypothesis.

The environment that comprises outer space has been presented to prepare us for a more meaningful discussion of the technical aspects of space exploration. Now that a firm footing of knowledge has been established, we will proceed with a thorough examination of the technologies of the space age.

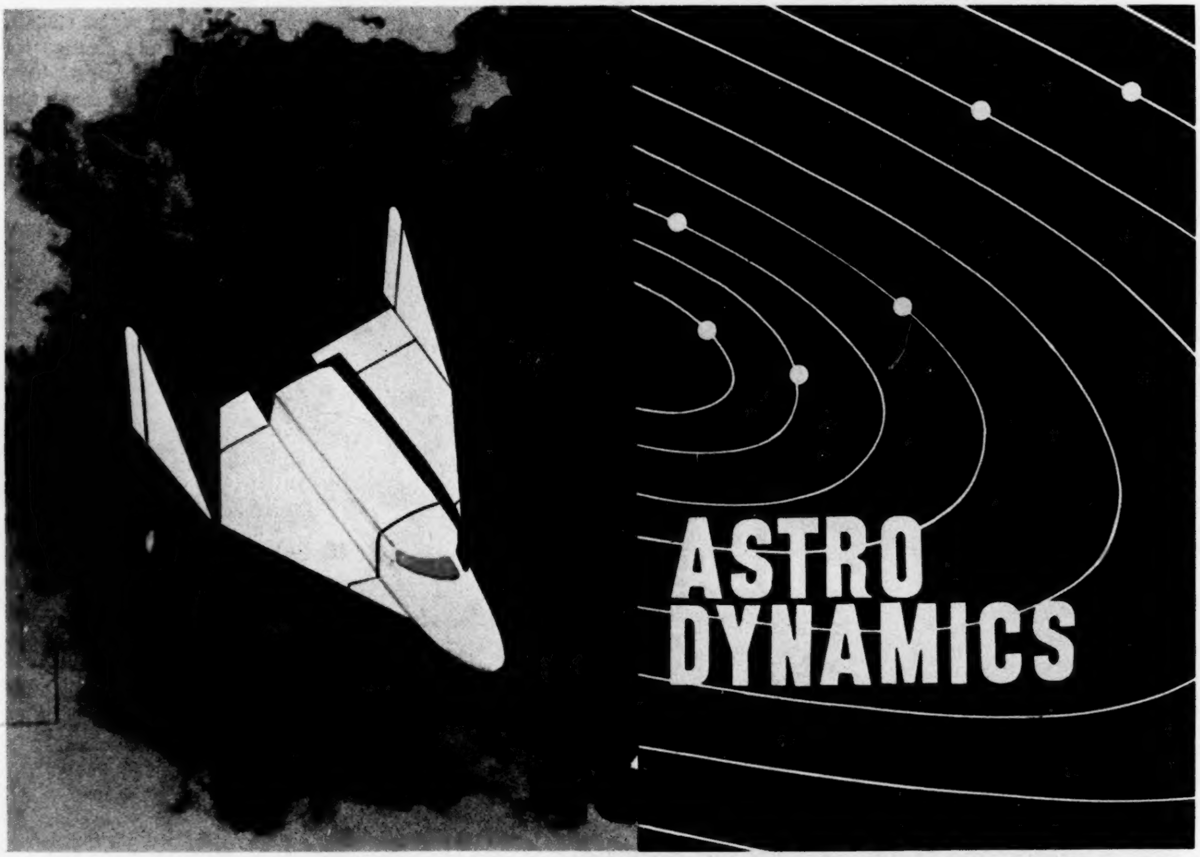
CHAPTER 5

ASTRODYNAMICS

GENERAL

Astrodynamics is the application of the general laws of motion to objects moving through space. The launching of Earth satellites has ushered in a new era of importance for this scientific study of the motion of bodies in space. Motion is a characteristic common to everything from minute electrons to planets spinning about the Sun. There is nothing in the universe so permanent, so stable, or so stationary that it does not have some sort of motion.

Let us therefore begin our whirlwind tour of the mechanics of orbits and their determination, including the rendezvous problem, with a brief review of the basic laws of motion which evolved from the work of Kepler and Newton.



FUNDAMENTAL LAWS

Of all the early astronomers, Kepler was perhaps the most productive. Based upon the observations by astronomer Brahe and the heliocentric theory of Copernicus, Kepler derived three extremely useful laws. His First Law states that the orbits of the planets are ellipses with the Sun at one focus. The Second Law of Kepler states that the imaginary line joining a planet to the Sun sweeps through equal areas in equal times. In other words - the shorter the distance to the Sun, the faster the planet travels in its orbit. The Second Law can be easily derived from the principle of conservation of angular momentum. The Third Law, called the harmonic law, states that the periods (the times required for one revolution of the planets around the Sun) are related to the mean distances of the planets from the Sun.

Newton found Kepler's Law to be just special cases of his laws of gravitation and motion. He extended this approach to include any body moving in response to a central force. The effects of the masses of the bodies were also taken into consideration. These central force laws which govern the motion of planets about the Sun and explain the "orbits" of electrons in atoms are also valid for man-made satellites.

ORBITAL MECHANICS

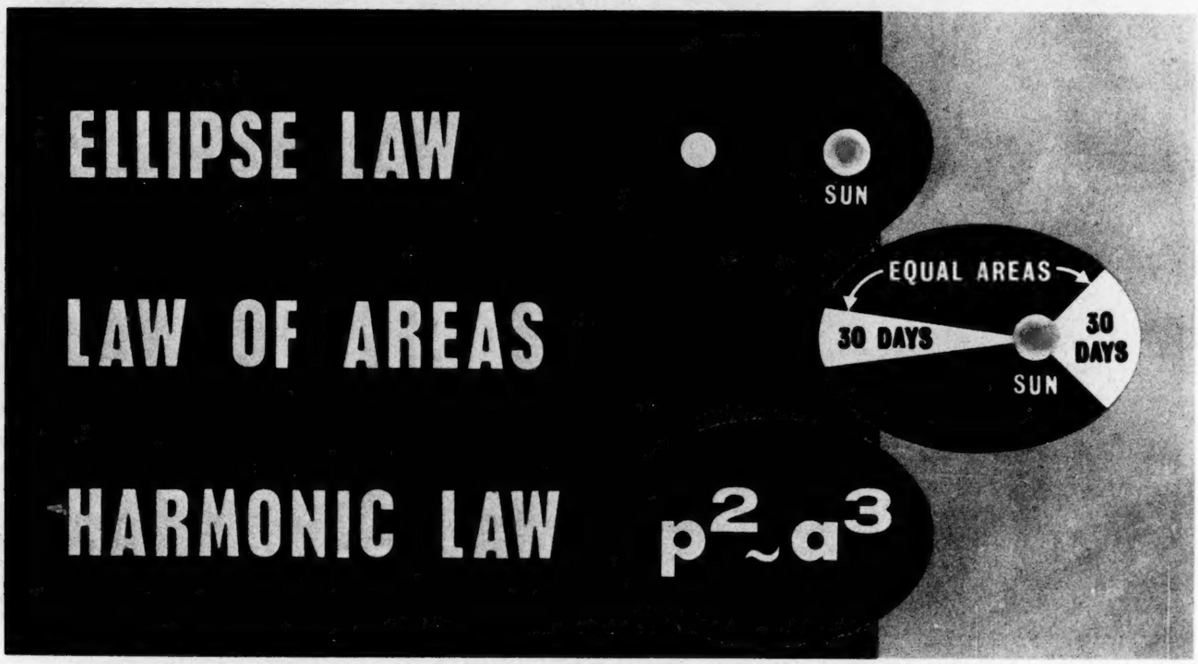
Analysis

The path that a body follows in space depends upon both the direction and speed of the body. It may follow a trajectory with unique beginning and end points (for example, from Earth to the Moon), or it may follow a cyclic path around a parent planet. Paths are usually closed such as ellipses and circles (a special case of an ellipse), or open (trajectories) such as parabolas or hyperbolas.

These basic types of paths are calculated by the techniques of celestial mechanics which employ Kepler's laws, Newton's laws of motion, and the universal law of gravitation.

In order to demonstrate the importance of Kepler's and Newton's laws today, let us work a problem of current interest.

Consider a situation wherein we wish to establish a satellite in a circular orbit that is synchronous with the rotation period of the Earth, that is, the satellite goes around the center of the Earth once every twenty-four hours. We must answer two questions. How high above the earth must the satellite orbit? And, what orbital velocity must we give the satellite?



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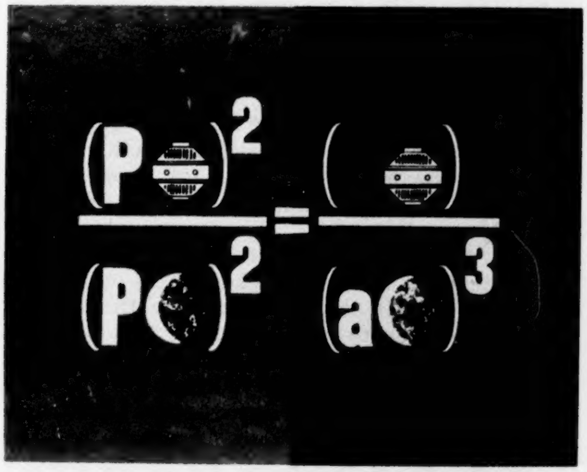

The easiest way to solve the altitude part of our problem is by using Kepler's third law. This harmonic law relates the ratio of the squares of the periods, $(P_1)^2 / (P_2)^2$, of two satellites to the ratio of the cubes of their mean distances, $(a_1)^3 / (a_2)^3$, from the center of force.

$$\frac{(P_1)^2}{(P_2)^2} = \frac{(a_1)^3}{(a_2)^3}$$

Equation (1)

In our case, to determine the altitude, we'll use our natural satellite, the moon, as the second orbiting body for comparison. In equation (1) substitute one day (twenty-four hours) for the period of the synchronous satellite, (P_1).

From experience we can substitute the moon's period of rotation (27.32 days) for (P_2). We might insert the moon's distance (approximately 239,000 miles) for (a_2) but to avoid a tedious operation with large numbers we can scale all distances to the lunar distance which can be set equal to unity. We can then solve for the satellite's distance (a_1) as a fractional part of the scaled lunar distance thereby obtaining a separation distance of 0.11 lunar distance (26,290 miles from the center of the Earth). Subtracting the radius of Earth (3960 miles) from the separation distance will give us the required orbital altitude of 22,330 miles above the surface of the Earth for a synchronous satellite.

$$\frac{(1)^2}{(27.32)^2} = \frac{a^3}{(1)^3}$$

$$a = 0.11$$

$$= 26290 \text{ miles,}$$

OR 22,330 MILES ABOVE EARTH'S SURFACE

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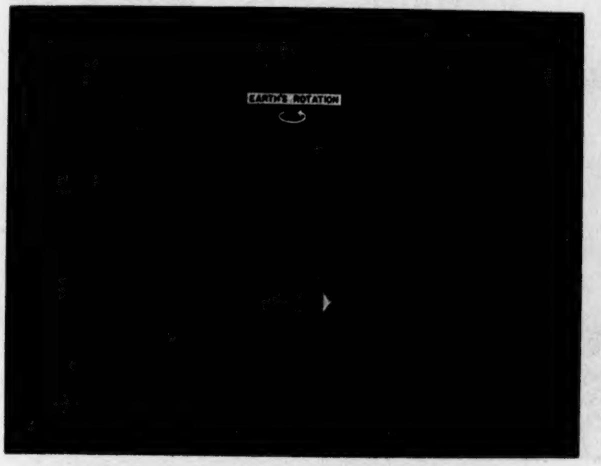


If we wish to establish a satellite with a synchronous period that also remains "stationary" over a fixed geographical point we must meet three requirements: (1) The period of rotation must be synchronous with the Earth's rotation (24 hours), (2) The orbital plane of the satellite, which includes the center of the Earth, must coincide with the Earth's equatorial plane to insure no North-to-South relative motion of the satellite, and (3) the satellite must orbit in the same direction as the rotation of the Earth (from West to East). When these three orbital conditions are met at an altitude of 22,330 miles over the equator we have what is popularly called a synchronous orbit. Such a satellite, with only occasional adjustments, can remain nearly stationary over a fixed geographical point on the equator, that is, be geostationary.

As the second requirement of our problem (to maintain the synchronous altitude) the satellite must have the proper orbital velocity (or inertia) to offset the gravitational attraction of the Earth. To calculate this velocity we counterbalance the attractive force of gravity by an equivalent centrifugal effect. The satellite falls in a curve that parallels the curvature of Earth, hence it keeps a constant altitude despite "falling" under the force of gravity.

This balance can be represented by an equation: The left side of the equation (2) represents the centripetal force and the right side represents gravitational attraction with its dependence on the square of the distance of separation between mass centers.

$$\frac{m v^2}{r} = \frac{mg R^2}{r^2}$$

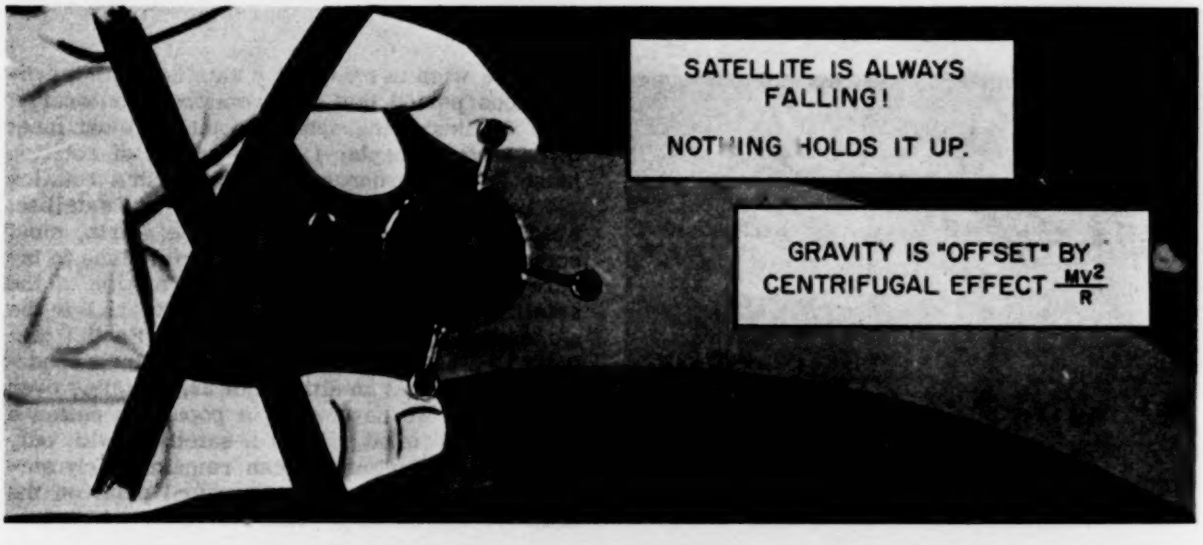
Equation (2)

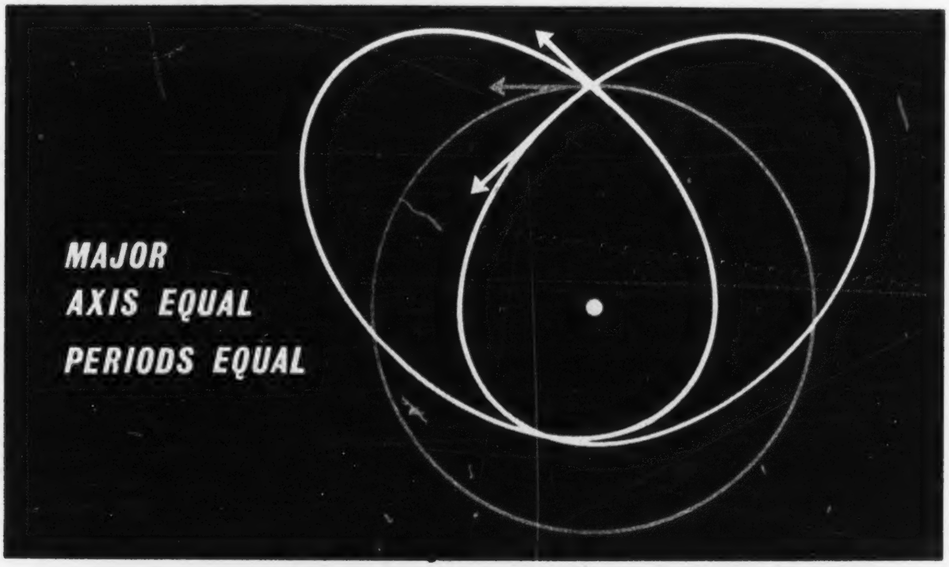
We can solve equation (2) for the required synchronous velocity v of a satellite of mass m since we know r, the satellite's separation distance (26,290 miles). R is the Earth's radius (3960 miles), and g is the gravitational acceleration (about 32.2 ft/sec^2 at the surface). With these substitutions and proper conversion of units, we obtain v= 1.91 mi/sec. (6,876 mi/hr). This is the velocity necessary for a satellite to orbit in a near circle at 22,330 miles above the surface of the earth with a synchronous 24-hour period of rotation.

Establishing Orbits

The classical procedure to establish an artificial satellite in orbit about the Earth consists of three phases: (1) launch, (2) programmed maneuvers to the injection point, and (3) injection into orbit.

In order to lift the vehicle quickly out of the atmosphere for efficient rocket operation, a space vehicle is usually launched in a vertical mode. Then it is maneuvered by reaction controls along a flight path which takes it to the injection point at the desired altitude. For maneuvers to the injection point, there is an important velocity component that cannot be ignored. This is the velocity component of the spacecraft due to the Earth's rotation on its axis. Dividing the circumference of the Earth at the equator (about 25,000 miles) by its period of rotation (24 hours) we find that a point on the equator moves at about 1,040 mph in an Easterly direction. At latitudes either above or below the equator, the easterly velocity of a point is determined roughly by multiplying the equatorial velocity by the cosine of the latitude. This velocity decreases as we go either North or South until, at the poles, it becomes zero. At the injection point, after programmed maneuvers place the vehicle in the proper altitude and heading, the injection propulsion stage is fired to impart the exact velocity required to establish orbit.


SATELLITE IS ALWAYS FALLING!
NOTHING HOLDS IT UP.
GRAVITY IS "OFFSET" BY CENTRIFUGAL EFFECT $\frac{MV^2}{R}$



If at injection the direction of the velocity vector is horizontal with respect to the Earth (tangent to a concentric circle for that altitude), and if the magnitude of the velocity is precisely correct for that altitude, the satellite will enter a circular orbit. However, if the direction of the velocity vector is inclined to the horizontal the satellite will enter an elliptical orbit. Its apogee (point farthest from Earth) will then occur either forward of the injection point if the velocity is inclined upward from the horizontal, or rearward of the injection point in the orbit if the injection velocity is inclined downward. A tilt error of only 1.5 degrees can cause a difference of 100 miles in apogees compared to a circular orbit. A velocity magnitude error of only 2 ft/sec will give a difference of about 1 mile in comparative apogees.

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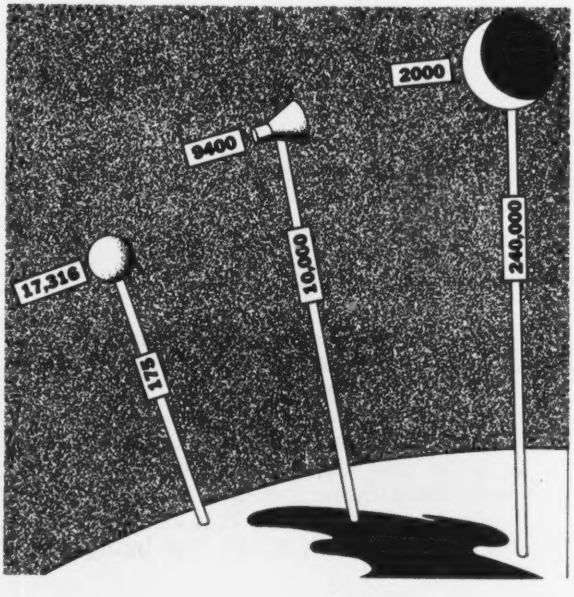
Different orbital velocities are required to establish circular orbits at different altitudes above the Earth. In each case, the injecting stage of the booster must accurately produce a specific velocity for circular orbit. For example a satellite close to Earth at an altitude of about 175 miles requires a velocity for circular orbit of about 17,300 mph (5 mps). For one at 10,000 miles the velocity requirement drops to about 9,400 miles per hour. The Moon, our natural satellite at about 240,000 miles, possess an orbital velocity of only about 2,200 miles per hour.

These variations in orbital velocity requirements at different distances from the Earth result from the decrease in gravitational attraction with distance. Gravitational force must be counterbalanced by centrifugal effect or the body falls to Earth. Since gravitational force decreases as we go farther from the Earth, less centrifugal effect is needed to counter-balance it. A freely moving object in orbit moves at slower velocities as its distance from the center of force increases.



This is simply a consequence of gravitation and the principle of conservation of angular momentum as stated in Kepler's second law.

Changing Orbits

Now let's examine a few hypothetical orbit changes in space. Assume that we have been able to put a satellite into orbit at an altitude of 300 miles where it would travel nearly five miles each second. At this altitude and velocity the curve of the satellite's orbit is the same as the curvature of Earth. So, in essence, the satellite falls around the earth at a constant altitude (it is in circular orbit). Nothing holds it up; it is continually falling at the same curvature as the Earth's surface.

Suppose we alter the velocity of this satellite by firing retro-rockets to slow it. The satellite's velocity is thereby reduced from the required five to three miles per second. The centrifugal effect decreases and the balance with gravity is upset. The satellite will descend into the Earth's atmosphere where it either will disintegrate or impact with Earth.

Suppose we fire the rockets in a direction to increase the satellite velocity to about 6 miles per second. The centrifugal effect will increase. Once again the balance between gravity and centrifugal effect has been upset and the satellite will move out to a greater distance. Near apogee the gravitational pull of the earth has decreased, but so also has the satellite's velocity. The velocity decreases, however, at a greater rate as the kinetic energy of the satellite is exchanged for potential energy of position in the Earth's gravitational field. When the centrifugal effect becomes less than the effect of gravity, the satellite reaches apogee and begins to move towards Earth. As it moves downward, its velocity increases because of the change potential energy into kinetic energy until at perigee (point closest to Earth) it has regained its original 6 miles per second. Then this cycle repeats. The original circular orbit has become elliptical.

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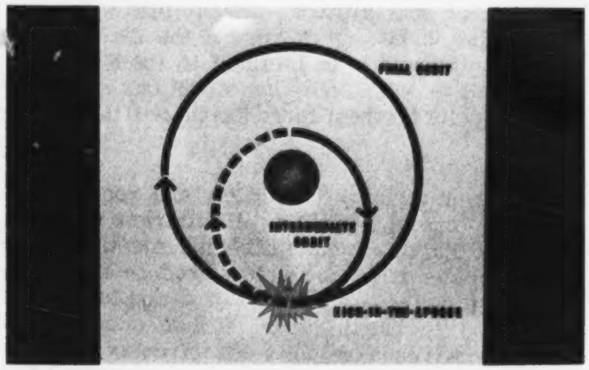
If one applies the increased thrust at the apogee of an elliptical orbit it is possible to change an elliptical orbit into a larger circular orbit. This method of boosting at apogee is one way to achieve a higher orbit. It is frequently called the "kick-in-the-apogee" technique.



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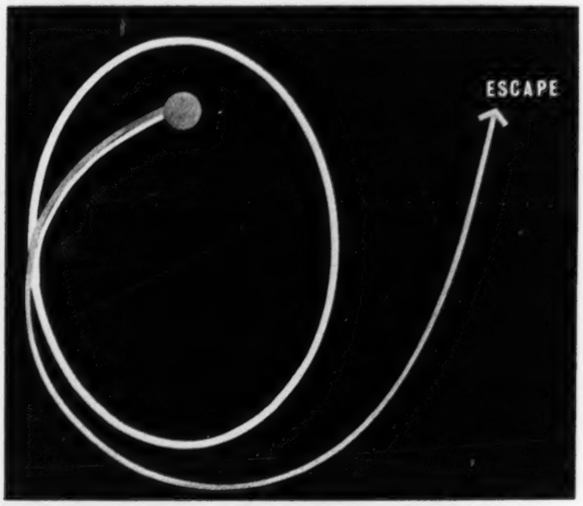
Escape Velocity

To better understand the critical influence of velocity on orbital paths, let's consider other trajectories of a space vehicle. A spacecraft will assume an open-ended path if its velocity equals, or exceeds, "escape velocity". Escape velocity is that threshold velocity with which the body must move if it is to overcome gravity and escape nearby bodies. It is a different velocity for every point in space. For interplanetary trips the spacecraft must be accelerated to above escape velocity from its parent planet. Escape velocity from launch is a function of the size and mass of the body from which the satellite it to escape. For example, to escape the Moon, which is light and small, will require an escape velocity of about 1.5 miles per second. For a vehicle launched from the surface of the Earth the escape velocity is about 7 miles per second; from massive Jupiter it is about 37 miles per second.

At precisely escape velocity, the body takes up a parabolic trajectory in space. Velocities greater than escape velocity cause the body to arc into space on a hyperbolic path. Velocities less than escape velocity result in closed paths. These are usually ellipses in which the satellite is bound to the planet by gravity. Escape velocity then is the dividing line between local flights and interplanetary flights to other celestial bodies.



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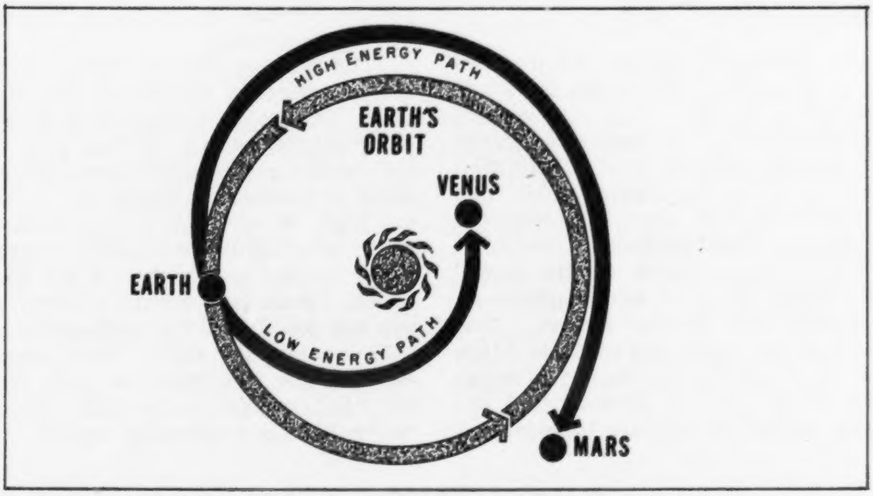
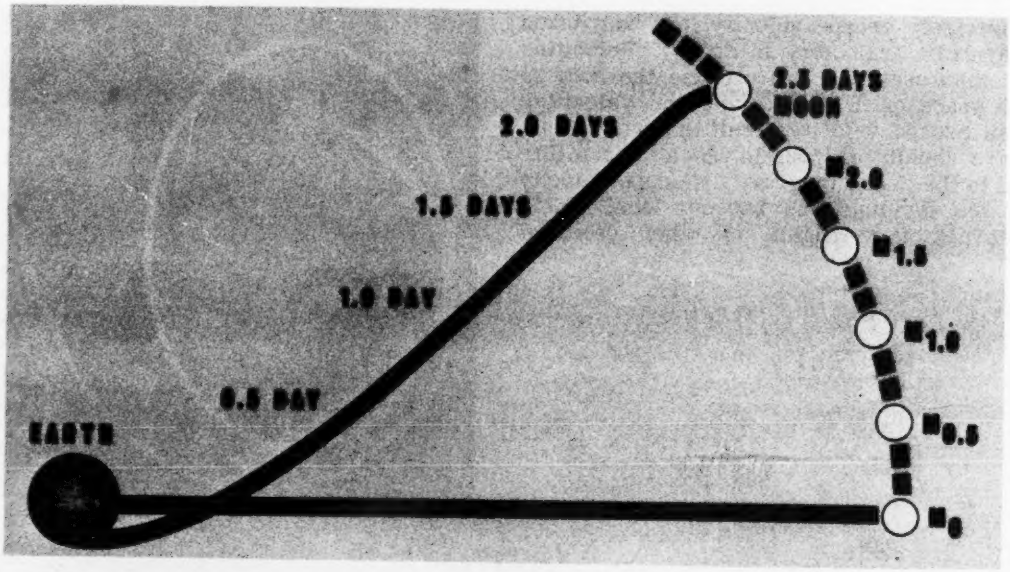


We have yet another velocity factor which must be considered on interplanetary flights beyond the Moon. This factor results from the Earth's orbital velocity about the Sun. While still on the launch pad, our spacecraft is already traveling at a velocity around the Sun at about 18.5 miles per second. This velocity component stays with any spacecraft that is in orbit about the Earth. However, if we use upper stages to propel the spacecraft to escape in the same direction as the Earth's velocity about the Sun we will give the spacecraft a greater velocity relative to the Sun than that of the Earth. The spacecraft would then move farther from the Sun than the Earth's orbit so it might rendezvous with an outer planet such as Mars. Conversely, if we used upper stages to propel the spacecraft to escape in a direction opposite to the Earth's velocity about the Sun, then the spacecraft will have a resultant velocity about the Sun less than that of Earth. It would then move into a path closer to the Sun so that it might rendezvous with one of the inner planets such as Venus.



Interplanetary Flights

The Ranger, Surveyor, Lunar Orbiter and Apollo programs to explore the Moon are steps toward interplanetary travel. Let us examine the velocity requirements for a flight from Earth to the Moon. Assume that we have established a spacecraft in a 300 mile parking orbit with the intent to impact on the Moon. At 300 mile altitude, a velocity of about 35,000 feet per second is necessary to leave Earth for the Moon. The trajectory shown is as it would appear to an observer sitting over the North Pole. The cis-lunar portion of the trajectory between Earth and the Moon is completed in about two days. Then the effect of the Moon's gravitational attraction becomes evident as it causes the terminal portion of the spacecraft's trajectory to curve into Moon impact.

The importance of slight variations in the initial velocity necessary for transfer into a moon trajectory should be emphasized. For a velocity that is only 35 feet per second too low, the impact point moves from Moon center to the Western limb of the Moon; for 50 feet per second too high, it moves to a point beyond the Eastern limb. Even with these small changes in velocity, some impact points would not be visible from Earth. However, errors of from -35 to +50 feet per second around the designed transfer velocity will accomplish simple lunar impact. Even so, you can see that there is little room for error. In practice, midcourse and terminal guidance corrections are normally applied.

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ORBIT DETERMINATION

Observations

Let us reconsider Earth orbits and see how they are described analytically. The computation of orbits is based upon the procedures formulated by early mathematicians, Gibbs . . . Laplace . . . Lagrange.

In general, the actual analysis of space flights consists of two major phases of computation. The first of these is the initial determination of the orbital elements, and the second is the improvement of the accuracy of the orbital elements.

One procedure to determine an orbit initially is to take three or more sets of observed values for the satellite's position and time-rate of change of position in any 3-dimensional coordinate system. From these observed values we can solve the differential equations of motion of the satellite. These equations of motion when integrated yield six constants which are usually called the

ORBITAL ELEMENTS of the satellite. The orbital elements analytically describe an orbit in space.

The six orbital elements generally used to describe an orbit about Earth at a designated time (EPOCH) are (1) INCLINATION, (2) SEMI-MAJOR AXIS, (3) ECCENTRICITY, (4) RIGHT ASCENSION OF THE ASCENDING NODE, (5) ARGUMENT OF PERIGEE and (6) MEAN ANOMOLY AT EPOCH.

ORBITAL ELEMENTS

- INCLINATION
- SEMI-MAJOR AXIS
- ECCENTRICITY
- RIGHT ASCENSION OF THE ASCENDING NODE
- ARGUMENT OF PERIGEE
- MEAN ANOMALY AT EPOCH

Orbital Elements

We will briefly examine these orbital elements in order to obtain a better understanding of their meaning and to see how they do indeed define an orbit.

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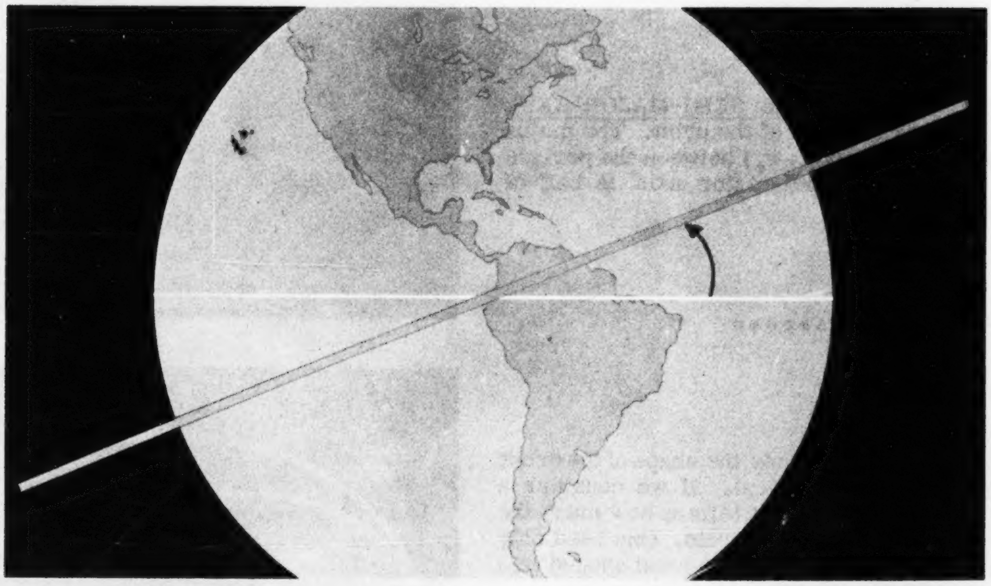


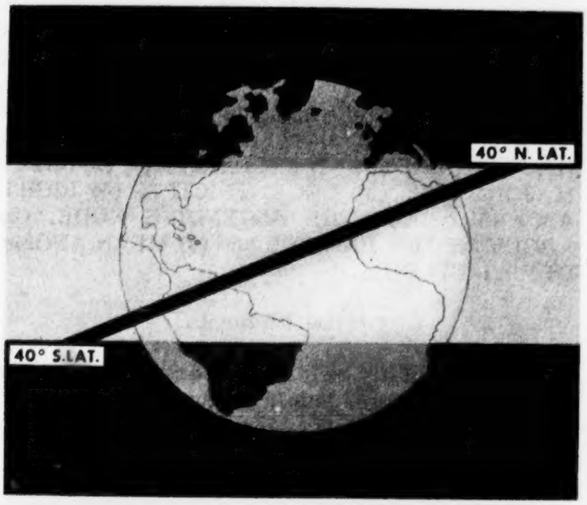
The first element is the INCLINATION of the orbital plane. Inclination is the angle between the plane of the satellite's orbit and the equatorial plane. The inclination determines the satellite's path over the surface of the Earth. Since the plane of the orbit must include the center of gravity of the Earth, the inclination determines the highest latitude that the ground path of the satellite traces on the Earth.

At one extreme is an orbit at zero degrees inclination (an orbit which is in the equatorial plane). Such a satellite will pass only over the equator.

At the other extreme is the polar orbit at 90 degrees inclination. The plane of a polar orbit includes both poles. A satellite in polar orbit will eventually pass over the entire surface of the Earth, since, as the satellite orbits in a North-South direction, the Earth is revolving on its axis in an Easterly direction. This orbit is advantageous in observing all of the Earth periodically.

Inclinations between these two extremes will cause the satellite to pass over only those points on the surface within the band of latitudes whose upper limits are determined by the inclination angle. At an inclination angle of 40 degrees to the equator the satellite will pass over the surface areas between latitudes of 40 degrees North and 40 degrees South.

One point should be emphasized again, namely, that it is not possible for a free moving satellite to travel along lines of latitude or to remain stationary over any geographical point, except as discussed earlier for equatorial points and a synchronous satellite. Since any orbital plane must also contain the center of gravity of Earth, the only line of latitude at which this condition can be met is an equatorial orbit. Any other set of conditions will project as a repetitive ground track pattern on both sides of the equator.



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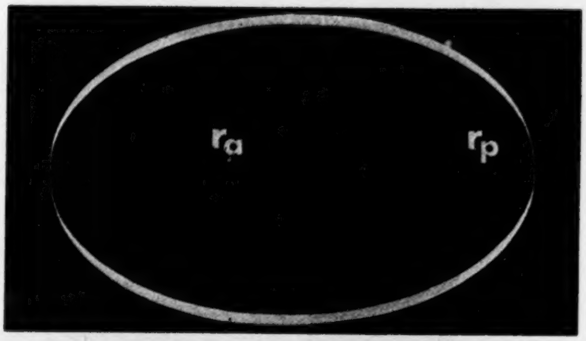
The next element, the SEMI-MAJOR AXIS, indicates maximum size of the orbit. The major axis is the distance ($r_p + r_a$) between the perigee and apogee. The semi-major axis is half of this distance.



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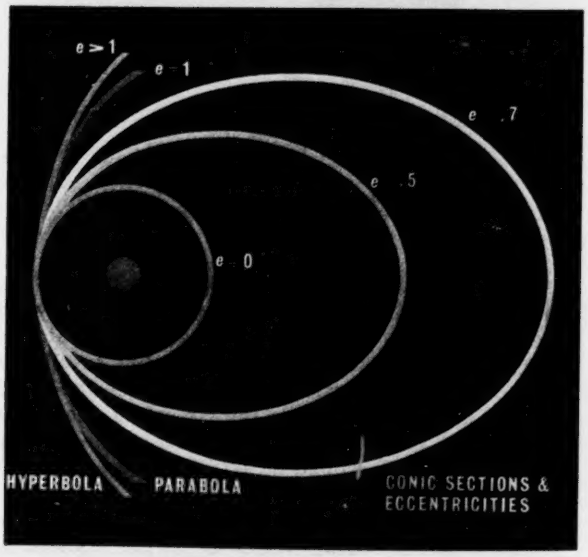
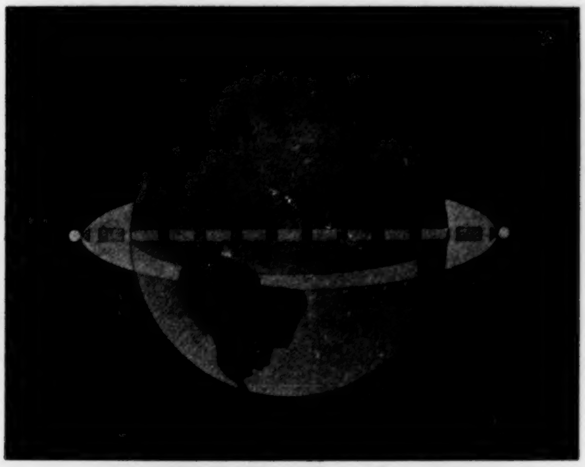
ECCENTRICITY defines the shape of the orbit, either circular or elliptical. If we consider a circular orbit as a basis, it tells us how much the orbit has departed from a circle. One need only know the satellite's perigee (r_p) and apogee (r_a) distances and this simple expression

$$e = \frac{r_a - r_p}{r_a + r_p}$$

to determine the value of eccentricity (e). Eccentricity tells us how elongated, or eggshaped, the orbit is.





Before we define our next orbital element it is necessary to discuss nodes. Nodes are the intersection points at which the orbital path of the satellite pierces the equatorial plane. The node formed when the satellite is traveling downward (North to South) is called the descending node while the node formed on the upward swing (South to North) is called the ascending node. The line formed by the intersection of the orbital and equatorial plane is called the line of nodes since it includes both nodal points.

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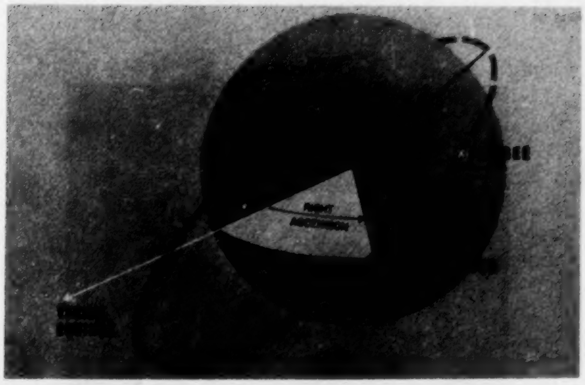

However these nodes do not project to any fixed geographical locations on the Earth's surface because of its rotation. Hence the orbital element called the RIGHT ASCENSION OF THE ASCENDING NODE is necessary to help define the orbit relative to the Earth. This element could be considered to be the longitude of the ascending node. It is the angle, measured at the center of the Earth, between the direction of the ascending node and a direction fixed "permanently" in space. This fixed direction is usually towards the first point of Aries (that is, the direction of the Sun when it crosses the equator at the time of the vernal equinox). This angle is measured in the equatorial plane in an Easterly direction. This element defines the orientation of the orbital plane without respect to the rotating coordinates of the Earth, or more correctly, it fixes the direction that the orbital plane faces in the Solar System relative to fixed stars. It can be projected to a geographical point on the equator for any specific time desired.

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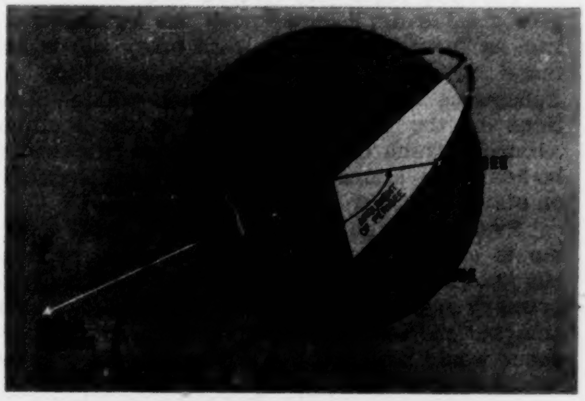
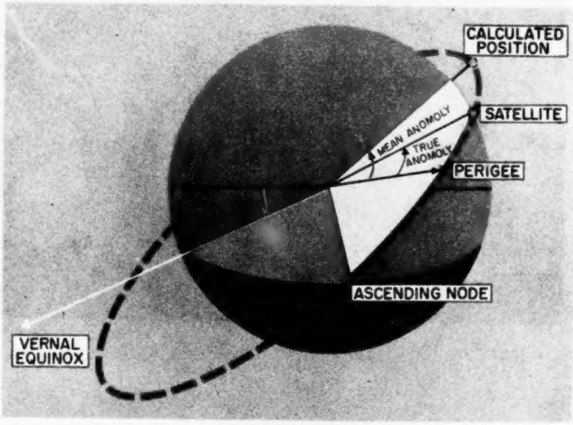


The relative orientation of the orbital path in its plane is accomplished by fixing the location of the major axis by measuring an orbital element called ARGUMENT OF PERIGEE. It is the angle, at the center of the Earth, measured in the plane of the orbit and in the direction of satellite motion between the ascending node and the perigee position. Because the Earth is not a true homogenous spheroid this element generally varies with time. That is, perigee is not fixed in space but gradually moves in the orbital plane due to perturbations.

The Mean Anomoly at Epoch is an angle calculated by taking the product of the mean angular speed over the orbital period by the time elapsed at Epoch (that is, the time of interest) since perigee passage. The actual angular position of the satellite relative to perigee is called the True Anomoly, and may be predicted from the mean anomoly from the known relationships of geometric figures. To predict where the body will be at any future time, a Mean Anomoly is calculated by using the Mean Angular Movement from the perigee point and the elapsed time from perigee. The corresponding true anomoly is then determined, which provides the predicted position of the satellite.

As discussed, these six orbital elements do define an orbit by defining size, shape, path over the Earth's surface, orientation in the solar system, and the orientation of the major axis in the orbital plane. Furthermore since the elements are constantly changing they must all be related to a common time of observation or prediction called EPOCH.



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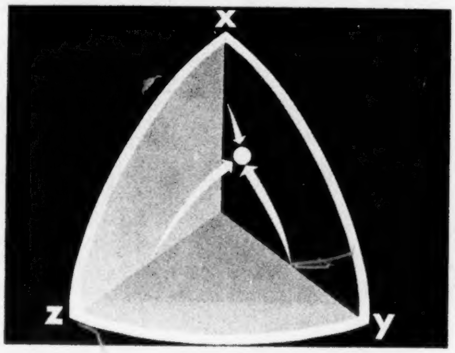
Orbital Computations

With the orbital elements explained, we can now represent the orbit in any particular coordinate system. One should choose the most convenient coordinates for the job. A heliocentric coordinate system with the Sun as the origin would be most useful for interplanetary space flights, while the geocentric coordinate system would be preferred for Earth satellites.

When we have transformed the measurements of the elements into the desired coordinate system we can compute (usually with the aid of high speed computers) the future values of the elements for a particular time. We observe the elements at this time and check our predictions.

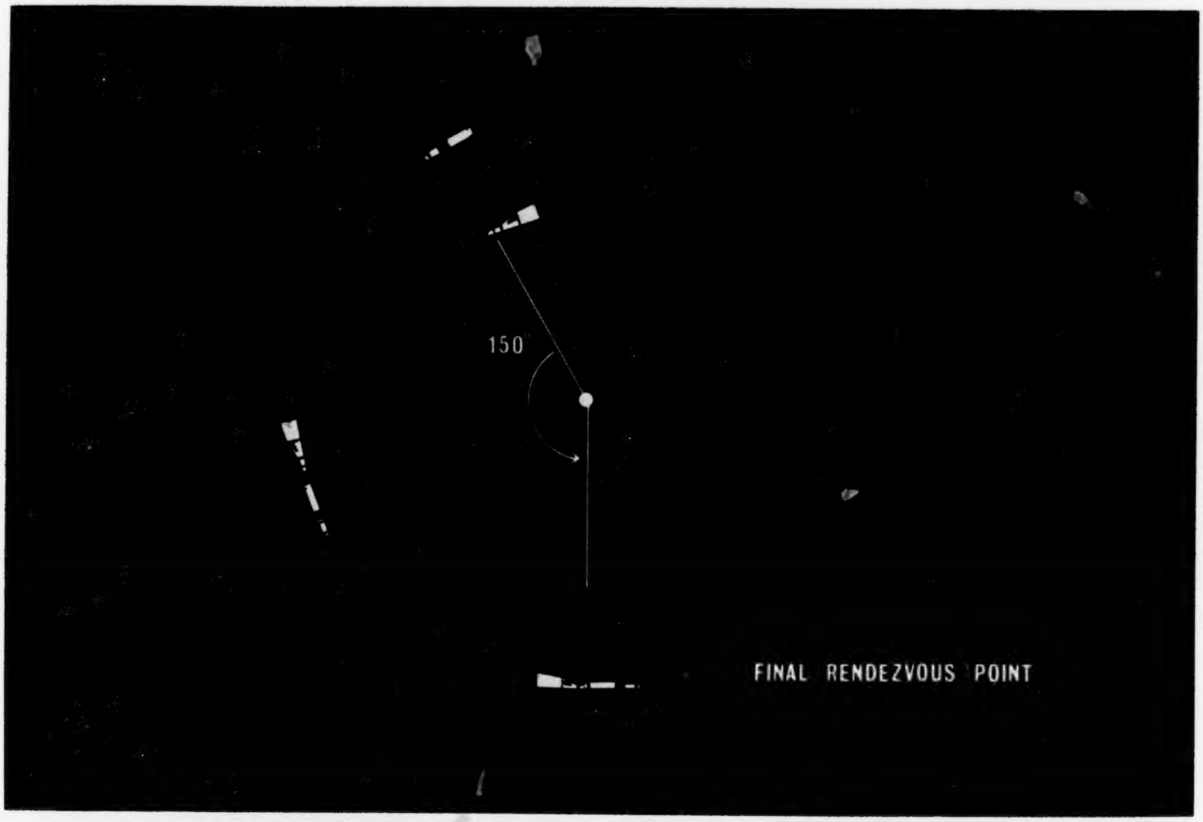
Then we begin the second step in orbit analysis: improvement of the initial elements. By comparing observed and computed values for a common time, we obtain correction increments. These increments are again used to improve or correct the computed values. This comparison must be a continuing process because of the many disturbing influences on the orbit, called PERTURBATIONS, that cause departure from an idealistic solution.

These perturbations include (1) effects of a non-homogenous, non-spheroidal Earth, (2) influence of the Moon, (3) drag on the satellite due to minute air resistance and magnetic fields, and (4) the pressure of radiation and solar winds from the Sun.



The pre-calculated values are tabulated to give a table of predicted positions for the satellite as functions of time. . .in other words, we make up an EPHEMERIS for a satellite. An Ephemeris is a tabulation of time-related positions of the satellite similar to the Nautical Almanac which catalogs information on celestial bodies. An almanac is, in fact, an Ephemeris on stars and other bodies.

Even with high speed computers, orbit analysis is a laborious and time-consuming process but knowing the exact position of a satellite is of primary importance. Without such precise orbit analysis the use of satellites for practical purposes would be ineffective and rendezvous of space vehicles would be severely limited.

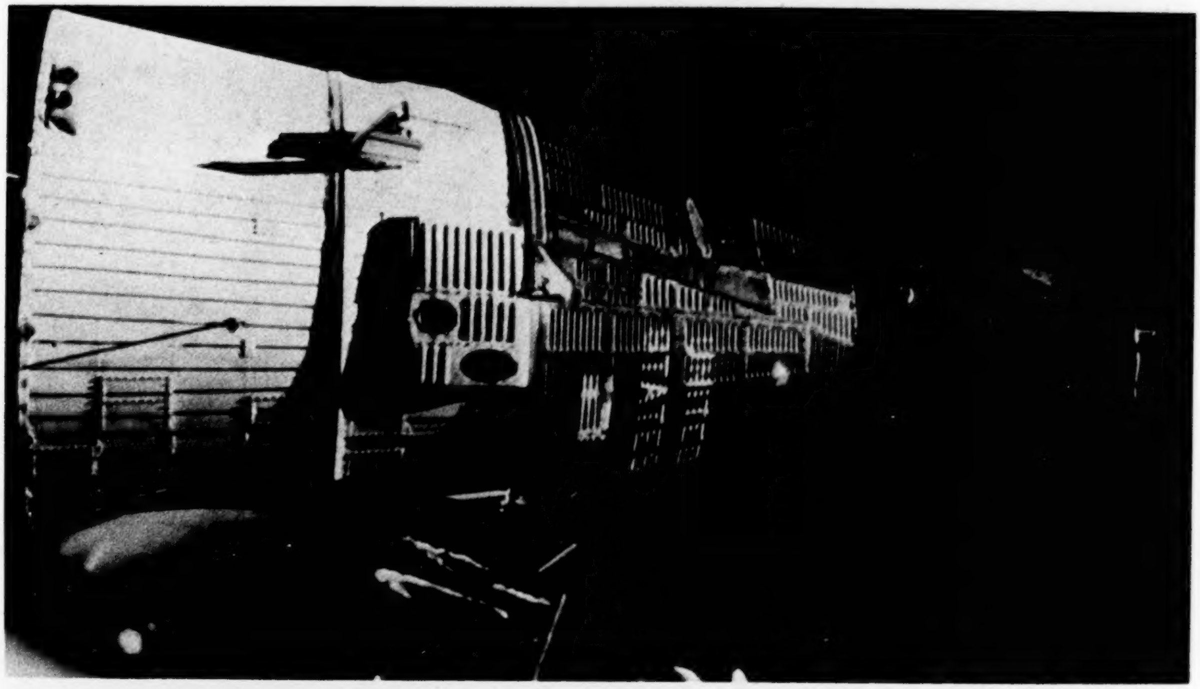


Space Rendezvous

Rendezvous of space vehicles is a phase of space operations that is becoming most important to the future of manned space flights. It was one of the major objectives of successful Project GEMINI. It is essential to the success of the planned flights of American astronauts to the Moon and back, Project APOLLO.

The inherent difficulties with space rendezvous arise because two bodies with high velocities, and therefore large kinetic energies and momentum, must be maneuvered to arrive at the same place, at the same time, moving in the same direction, with the same speed. As one indication of the complexity of the problem, it takes sixty thousand times more energy to deflect an orbiting spacecraft than it does to deflect an automobile (traveling at 100 mph) through an equal momentum change. Further complications exist since energy for maneuvers to achieve rendezvous must be accurately applied at critical times in the orbit.

Let us examine the general approach used successfully in the GEMINI rendezvous flights. First of all, an ATLAS booster placed on an AGENA target into a 161-mile circular orbit with an inclination of about 28.87 degrees. During the first orbit of the AGENA, its orbital elements were precisely determined. About 4 minutes after the AGENA completed its first orbit and passed near the launch site, the GEMINI interceptor was launched into a lower orbit with nearly the same inclination as AGENA. The GEMINI orbit was not circular, however, but elliptical with an apogee at 141 miles and perigee at 87 miles. Because its average altitude was lower than that of the target, the interceptor by Kepler's law had a shorter orbital period (by about one minute) than the AGENA. So, although inserted about 1200 miles behind the target, GEMINI overtook the AGENA at the rate of about 4 degrees or 300 miles per orbit. While this chase progressed, the orbital elements of each vehicle were further checked. The GEMINI made plane changes while the catch-up rate was adjusted by changing its



perigee. When within about 250 miles of the target, rockets on the GEMINI were fired near apogee to circularize its orbit at 141 miles. Again, because there was still a difference in altitudes, the GEMINI had a shorter period and continued to close on the AGENA. At about 200 miles the GEMINI radar acquired the AGENA. Shortly thereafter, while both vehicles were still 15,000 miles and nearly 3/4 of an hour from the final docking point the GEMINI astronauts initiated thruster control. Near interception the spacecraft were roughly 20 miles apart with a closure rate of about 40 miles per hour. The astronauts could clearly see the AGENA. as they came nearer, the closure rate was reduced. From about 50 feet apart until final docking the rate was set at a relatively constant 1/2 foot per second.

Upon docking, the GEMINI and AGENA were mated physically and electrically so that the astronauts could utilize the AGENA's restartable rocket for further maneuverings. The GEMINI successes in the rendezvous technique marked a long stride forward toward the APPOLO Moon Project and showed conclusively that astronauts could not only sail the starry oceans but bring their ships to dock in space.

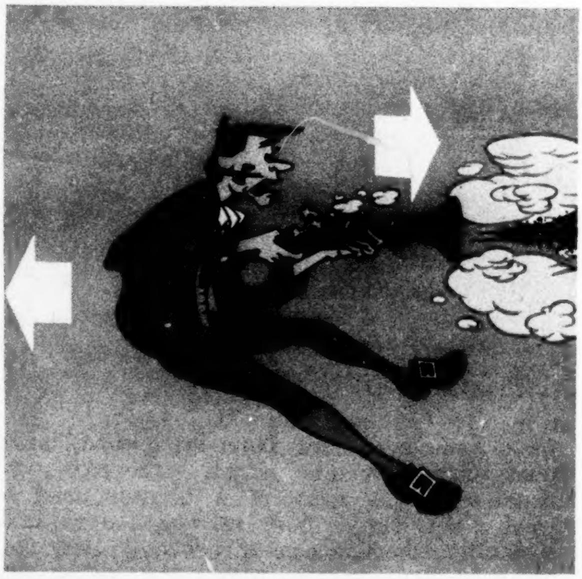
CHAPTER 6

ROCKET PROPULSION

GENERAL

Since rockets represent the only known means of propulsion for the exploration of space, the study of rocket propulsion is basic for an understanding of vehicles which carry men or instruments into space. A rocket propulsion system carries all the material required for its operation; it is a self-contained power plant. In one sense this represents a drawback because it must carry all the propellant required for the complete mission. Hence, the useful payload of a rocket is but a relatively small portion of the total weight of a rocket at liftoff. However, in an advantageous second sense, rockets are not dependent on their environment for power and can penetrate into deep unknown areas of space.

Rocket engines are a sub-division of the broad classification of engines called reaction engines. The principle of these engines is stated in Newton's third law of motion, ''for every action there is an equal and opposite reaction''.



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A rocket engine accelerates a mass of material (propellant) and then expels it at a high velocity to cause reactive forward thrust opposite to the propellant exhaust.

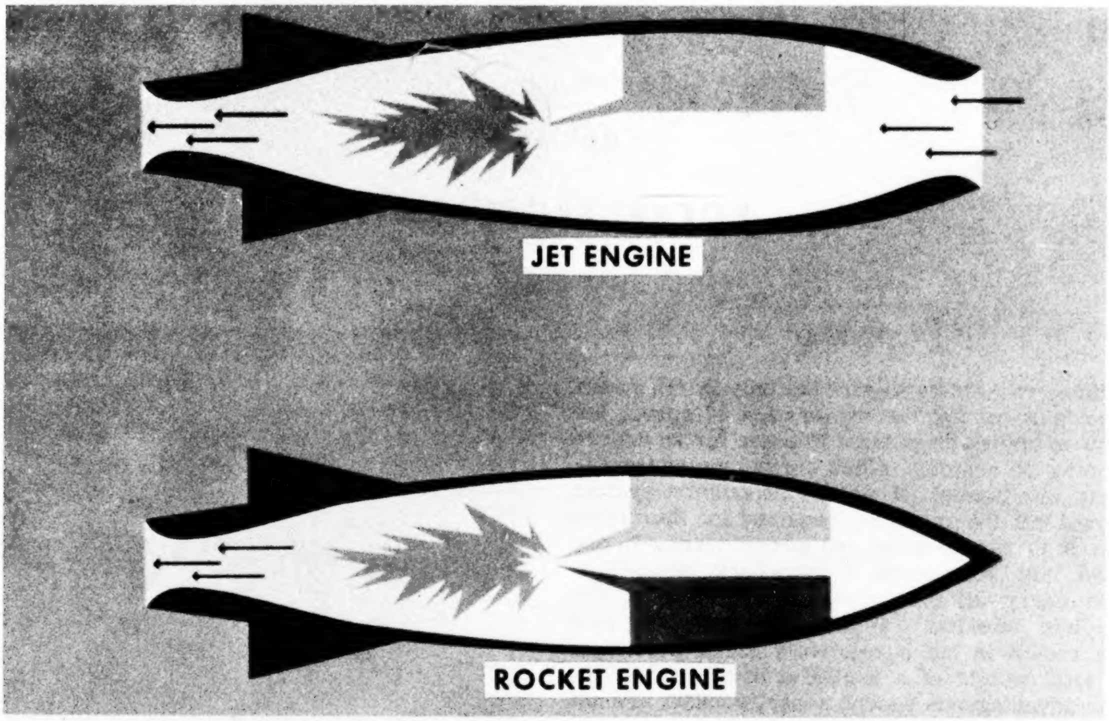
The rocket engine differs from other reaction engines such as a jet shown accompanying it in the illustration on the next page.

In the upper portion of the diagram we see the schematic of a jet which is a reaction engine that is quite familiar: for example, the German ramjet V-1 buzz-bomb of World War II, or today's turbojet commercial airliners. Although a jet carries its own fuel it depends upon the oxygen it compresses from the atmosphere to burn its fuel. A jet's operation therefore is limited to altitudes where there is sufficient atmospheric oxygen. A rocket, shown in the lower portion of the diagram, carries both fuel and oxidizer. It will function better in the hard vacuum of space than within the atmosphere.

The most frequently used terms to describe capabilities of rocket engines are THRUST, THRUST-TO-WEIGHT RATIO, SPECIFIC IMPULSE, EXHAUST VELOCITY, MASS RATIO. These characteristic terms will be defined briefly.

THRUST is the amount of reaction force developed through acceleration of the expellant material. Thrust is usually expressed in units of pounds. Thrust is most meaningful when it is related to the amountof weight that it must move, which leads directly to a comparison of thrust and weight.

The THRUST-TO-WEIGHT RATIO is the relationship between the amount of thrust developed, and the weight of the system. It is obvious that



for a vehicle to rise from the ground, thrust must exceed vehicle weight. Therefore, the thrust-to-weight ratio of a booster must be greater than unity. In space, weight as we know it, is diminished because of reduced gravity. For this reason, a system with a thrust-to-weight ratio of less than unity may be used to accelerate a payload in space.

The next term to consider is the SPECIFIC IMPULSE. It is one of the most important performance parameters used in discussing rockets. We must first, however, understand a more basic term, impulse. IMPULSE is the product of the force that is exerted on the system times the amount of time that the force is acting. It is found by multiplying the thrust times the burning time. Impulse, then is expressed in units of pound-seconds. SPECIFIC IMPULSE is the amount of impulse we derive from each pound of fuel burned; it is an indication of the relative fuel efficiency. Specific Impulse can be calculated by dividing the impulse by the weight of propellant consumed during the time of the impulse. It is easily seen that the units of specific impulse are $\frac{\text{pounds (force)-sec}}{\text{pounds}}$ and, although it is not strictly correct, it has become common practice to cancel out the pounds and express specific impulse in seconds.

Next we define EXHAUST VELOCITY, symbol C. This is the speed, usually expressed in feet per second, at which the exhaust material is expelled from the vehicle. One important fact to note is the relationship that exists between the molecular weight of the expelled gas and the specific impulse and the exhaust velocity. If the exhaust temperature remained constant and the molecular weight of the expelled gases decreased, the specific impulse and exhaust velocity would increase.

The final term is the MASS RATIO, ($\frac{M_o}{M}$), which formed by dividing the vehicle gross weight at launch (M_o) by the vehicle weight when its fuel has been expended (M). This ratio is always greater than one. For maximum velocity or range it should be as high as possible. Current rockets operate with a fuel mass ratio of about 5; in other words, a missile would carry enough propellant when fully loaded to account for 80 percent of its weight.

The generalized equation shown in the illustration is useful in relating some of the terms just discussed. It relates the velocity of the rocket (C) or the specific impulse (Isp) in terms or the natural logarithm of the mass ratio $(\frac{M_o}{M})$. Obviously the final velocity (V) is a very important parameter, because the greater the capability for final velocity is, the more energy there is available to put a payload into orbit, or to deliver a ballistic missile further downrange. As deduced from the formula, the final velocity can be expressed as a direct function of the exhaust velocity (C), therefore, an increase in exhaust velocity produces an increase in final velocity (V). Although it is less directly effective than an increase in (C), an increase in the mass ratio would also increase final velocity. In other words, the greater the percentage of weight of propellant carried, the greater will be the achievable final velocity.

$$V = C\,ln\left(\frac{M_o}{M}\right) = Isp\ g\,ln\left(\frac{M_o}{M}\right)$$

Examination of the second formula indicates that increasing the specific impulse (Isp) will also increase the final velocity. For this reason, much of the effort in the field of rocketry today is devoted toward the development of propellants with higher specific impulses. In the formula, "g" represents the acceleration due to gravity, and the final factor $(\ln \frac{M_o}{M})$ is the natural logarithm of the mass ratio.

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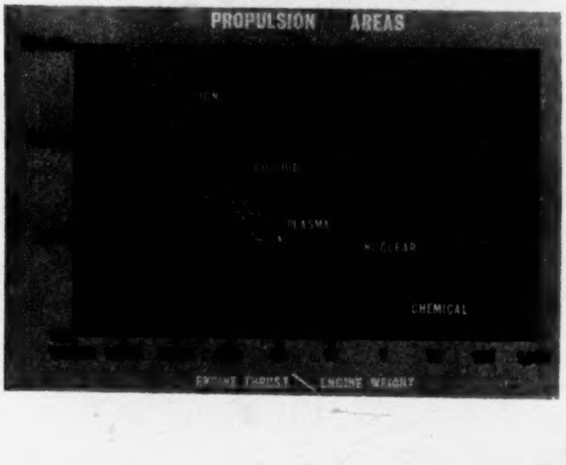
Before we discuss the various types of rocket engines we should recognize the predominant characteristics and advantages of each. The accompanying diagram shows the relationship between the specific impulse (Isp) and the thrust-to-weight ratio (T/W) for various categories of engines. It represents an overall view of the propulsion field. Engine thrust-to-weight ratio is plotted on the horizontal axis on a logarithmic scale. The specific impulse of the propellant engine combination is plotted on the vertical axis in seconds, again on a logarithmic scale. The characteristics for three general categories of engines - chemical rockets, nuclear heat transfer rockets, and electrical rockets - are plotted.



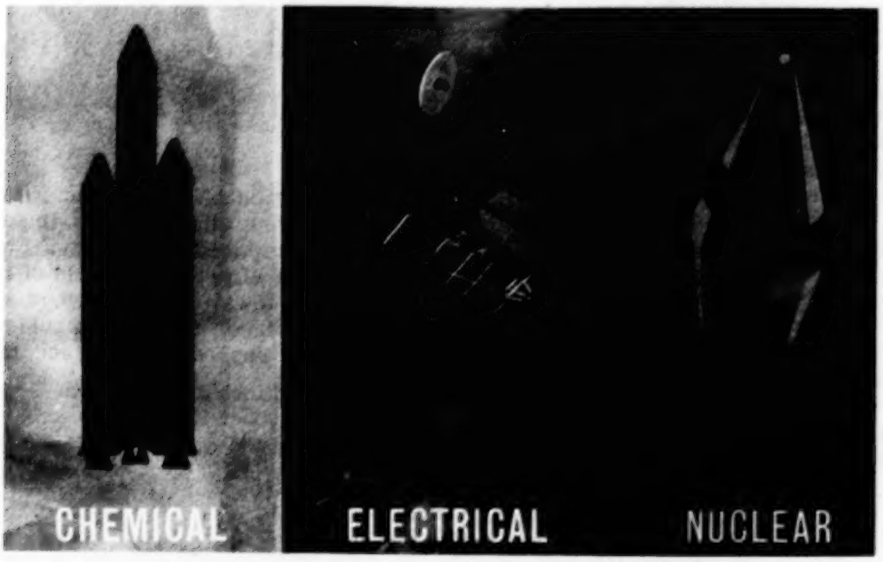
The block in the far lower right represents the general category of high performance chemical rockets.

The chart shows that chemical rockets possess very high engine thrust-to-weight ratios - on the order of several hundred; however, when compared with other types of rockets which are being developed, the specific impulse, or fuel efficiency, is relatively low.

Moving to the left down the scale in thrust-to-weight ratio we notice that nuclear engines have a thrust-to-weight ratio of the order of ten, quite reduced from chemical rockets. However, nuclear rockets possess comparatively higher specific impulses (they range from 800 to 1300 seconds). With such a considerable increase in specific impulse, nuclear reactors have definite potential for use in space. We will discuss them later in this chapter.

The group of engines in the upper left are the electrical rockets (the plasma or electromagnetic jet, the arc jet, the ion accelerators). Because their thrust-to-weight ratios are small fractions, they can never be used to left a vehicle from Earth, but because of their tremendously high specific impulse (currently testing at 5,000 to 10,000 seconds), they may achieve high velocities over extended periods of time. Many experts feel that they will afford a practicable means of propulsion for long range flights beyond the nearest planets.

With this brief introduction to the fundamental concepts and descriptive terms relating to rocket engines, we can proceed to a more detailed examination of the operating characteristics of the three types of rocket engines.



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CHEMICAL ROCKETS

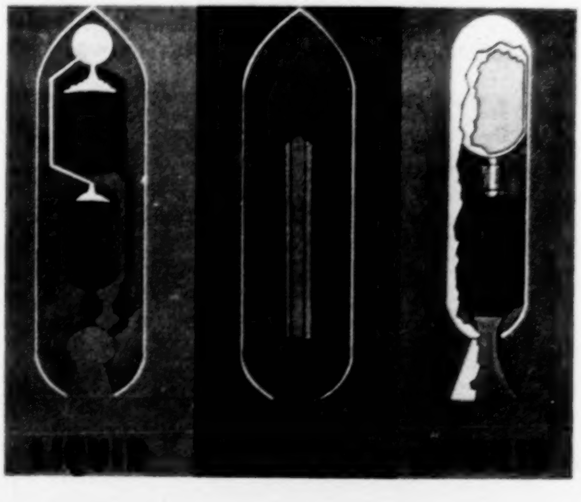
The chemical rocket satisfies two basic requirements for space flight propulsion. These requirements are (1) the ability to overcome the effects of gravity by boosting a vehicle from Earth, and (2) the ability to maneuver the vehicle in the vacuum of space. Although various other types of rocket engines have been proposed to accomplish the second of these requirements, the chemical rocket engine stands today as the only operational system that has performed both with a high degree of success.

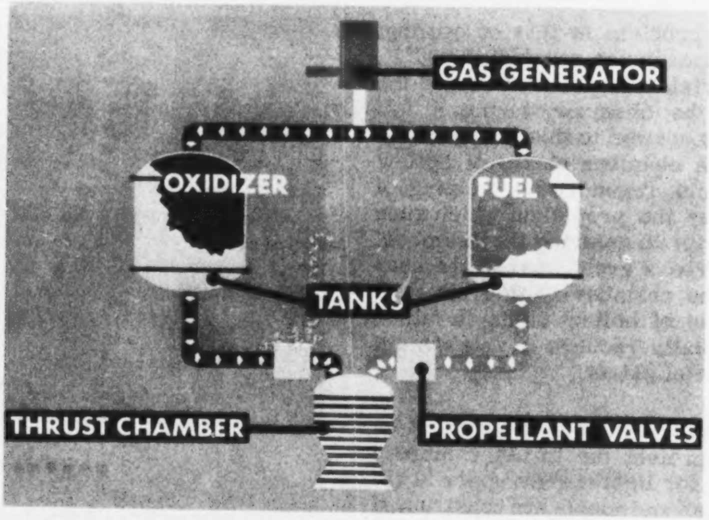
The chemical rocket combines a fuel and an oxidizing agent chemically to produce hot gas. This gas is expanded through a convergent-divergent nozzle which expels the material at a supersonic exhaust velocity to produce rocket thrust.

Chemical engines are subdivided into types according to the state in which the fuel and oxidizer are stored. The major categories are liquids, solids, and hybrids.

Liquid Propellant Rockets

Because of their high thrust-to-weight ratio, liquid propellant rockets have been used as the primary boosters on most of our space flights to date. They are also frequently used for maneuvering in space. The engines, excluding fuel, range in size from a small tennis ball to over 18 feet in length. Thrust also varies from a small fraction of-a-pound to over 1.5 millions of pounds.





Regardless of size, liquid propellant engines have essentially the same basic components: a thrust chamber, tanks filled with fuel and oxidizer, and a pressurization system or pumps to get the liquids out of the tanks.

Several major design problems exist with liquid rockets. To mention just a few . . .the problem of nozzle skirt-to-throat ratio, the problem of cooling, the problems of thrust vector control and avoidance of combustion instabilities.

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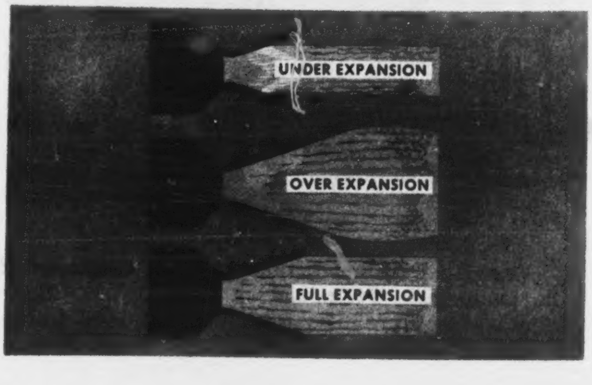
Nozzle design presents the problem of selecting the right ratio for the area of the nozzle skirt. Ideally, full expansion of the exhaust gases should be reached as the gases reach the end of the nozzle skirt. Nozzle design would be relatively simple if the external ambient pressure around the nozzle remained constant, however, such is not the case for a rocket that changes its altitude. The diagram shows the effects caused by using a nozzle in different pressure environments. In the lower portion of the diagram we see an engine operating in its design environment — at the proper altitude and pressure. The gases reach their full expansion just as they exit the nozzle, thus converting all of their heat energy to kinetic energy of the rocket vehicle.



In the center section of the diagram we see a nozzle operating at a higher altitude, and therefore at a lower pressure, than that for which it was designed. The gases still expand after they leave the nozzle. This energy of late expansion is wasted and does not contribute to rocket thrust.

In the upper portion of the diagram an engine is working at a lower altitude, and therefore a higher pressure, than the design pressure. The gases reach their full expansion before they exit the nozzle, and flow separation from the nozzle skirt occurs. The length of the nozzle beyond this point serves no useful function. In fact, it increases vehicle weight not only by its own wasted weight but also by the weight of any interstage structures necessary to accommodate this extra length.

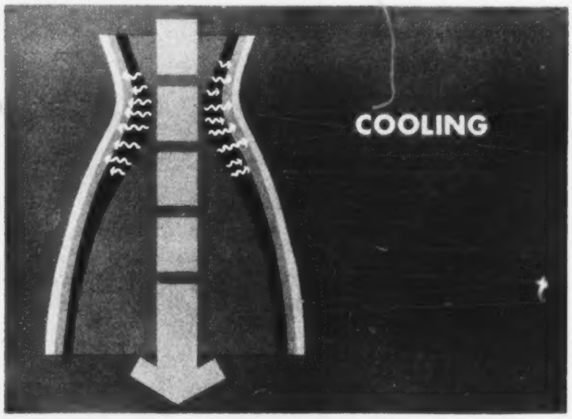
Because of these considerations nozzles are designed with different dimensions. For example, a booster engine has a skirt-to-throat area ratio of about eight for optimum use at low altitudes, while a ratio for use in an upper stage engine will range up to fifty, thereby allowing for much greater expansion at high altitudes.

A second design problem is that of cooling. With combustion temperatures reaching 5,000°F, there are few materials which can withstand the heat generated in the chamber during a full duration firing. One answer to this problem has been to fabricate the chamber skirts of hollow tubing. This permits regenerative cooling of the chamber walls by the propellant which runs through the tubing prior to entering the chamber. The propellant absorbs a great deal of the heat from the walls of the chamber in this manner. Furthermore, the use of hollow tubing in fabricating the skirt actually reduces nozzle weight compared to solid metal skirts.

Ablation is a other method of cooling that is sometimes used to protect the thrust chamber. It is most adaptable for light-weight upper stage engines. The chamber and nozzle are constructed of fiberglass impregnated with a plastic resin. The resin is vaporized by the hot combustion gases (thereby cooling the chamber walls). The vaporized resin chars and blows out with the exhaust gases. There is very little dimensional change in the nozzle during this ablative cooling process. Thrust chambers can also be cooled by radiating away excessive heat. For this purpose, a chamber is usually made of a very thin titanium alloy through which the heat passes easily. It is then radiated rapidly out into space.

The control of vehicle direction in space flight is of paramount importance at all times. One means to control the direction of thrust is by gimbaling the entire engine assembly including the exhaust nozzle. The propellant pumps and propellant tubes are usually gimbaled along with the thrust chamber to avoid use of high pressure flexible tubing to carry the propellant. Such tubing is difficult and expensive to manufacture. If there is only one engine for thrust control on the vehicle, such gimbaling gives gross control only about the two axes of rotation (pitch and yar axes - not roll). Small vernier engines can be added to improve fine direction control, including roll. The THOR booster rocket uses two of these verniers, each of which is rated at 1,000 lbs. of thrust, for fine direction control.

One flight control that is required for accurate space flight is thrust termination. This is relatively simple in a liquid system since all that is necessary to turn-off the engine is to stop the flow of fuel to the combustion chamber. Vernier engines can control the final trim in velocity quite accurately.



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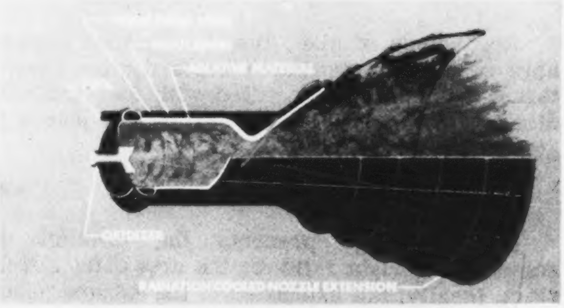

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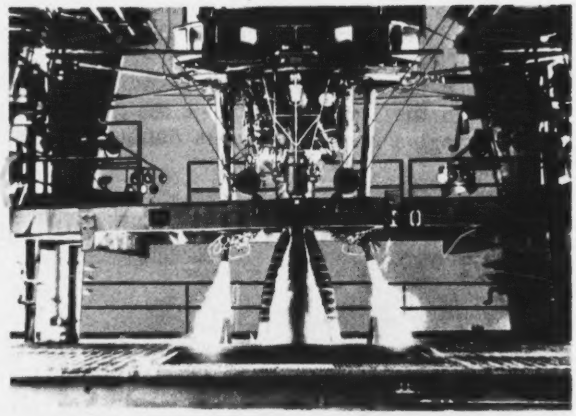
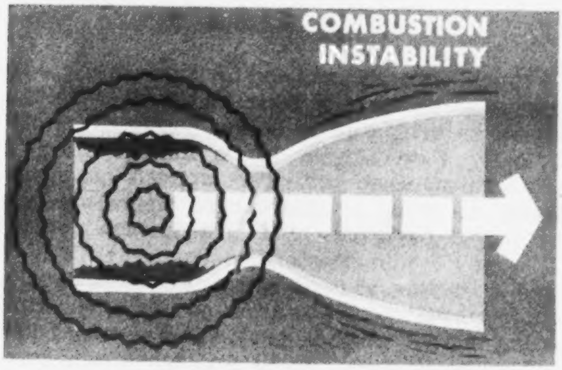


One final design problem to be discussed is the avoidance of combustion instabilities - those troublesome irregularities that can lead to lost thrust, or an explosion!



There are very few engines that, at one time or another during the development cycle, haven't been plagued by combustion instabilities. Combustion instability can occur when a small pocket of unburned propellant collects - possibly for just a period of microseconds - then explodes to set up uneven shock waves in the chamber. These might cause nothing more than an annoying acoustical effect - perhaps a high squeal; but more frequently they start a shudder or a tremor that feeds back into the fuel pumping system to cause uneven fuel flow to the chamber. This situation can avalanche and may eventually destroy the engine.

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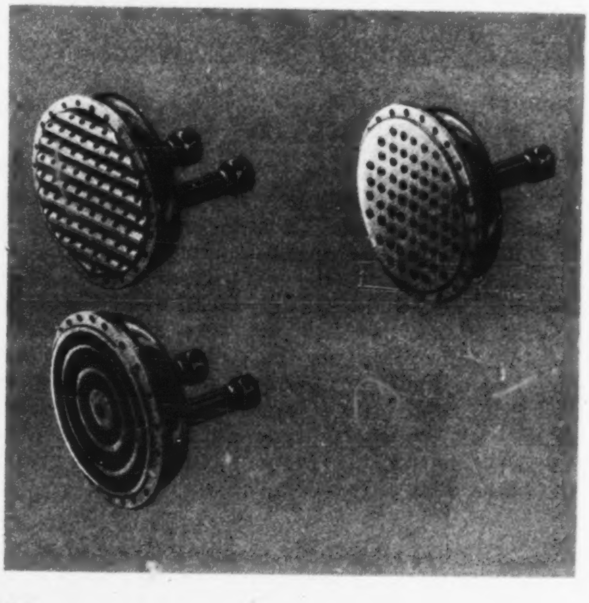
One of the first things to examine when combustion instability occurs is the design of the injector head used for mixing fuel and oxidizer. At first inspection of the accompanying diagram, injector heads appear similar to shower heads, but closer inspection shows them to be considerably more complex; the holes for fuel and oxidizer flow are of varying sizes and set at different angles. Frequently, there may be a series of baffles on the surface of the injector head to assist in directing the fuel flow. An injector head has a big job to do. It must place the propellant in the chamber at the right time, at the right place, mixed in the right proportions, and of the proper droplet size. The design of injector heads is, even today, a very empirical process. There are very few mathematical formulas that will tell an engineer how to design an injector head for any given engine. Much design success has been achieved through experience with injector heads, but their design is still more a matter of trial and error than anything else.



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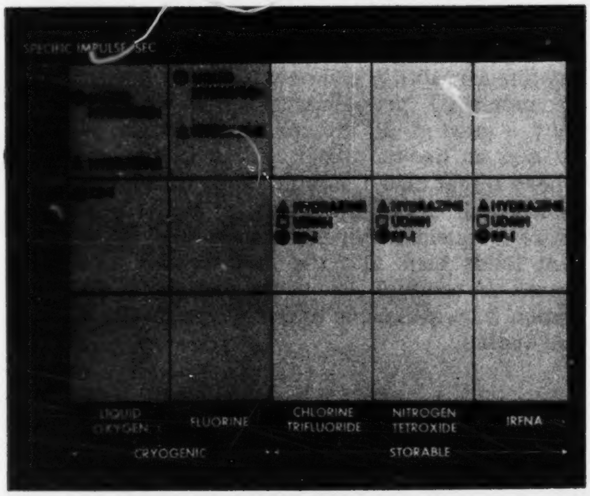
The propellants used in liquid engines are quite numerous. The diagram on the following page shows various combinations of fuel and oxidizers along with their specific impulses. The chart divides the oxidizers into the storable and the cryogenics.

CRYOGENIC indicates that a particular propellant exists as a liquid only at extremely low temperatures, such as liquid oxygen (LOX) which cannot exist above -297°F and liquid hydrogen which cannot exist above -423°F. The storage and handling problems with these materials are great, but they do have advantages in terms of higher specific impulses.

For storable oxidizers, chlorine trifluoride, nitrogen tetroxide, and inhibited red fuming nitric acid (IRFNA) are chosen as typical. Fuels commonly used with these are hydrazine and unsymmetrical dimethyl hydrazine (UDMH) of the ammonia family, and kerosene (RP-1). The specific impulse of (RP-1) increases from 250 seconds with storable oxidizers to 280 seconds when used with liquid oxygen; hydrazine and (UDMH) show similar increases. Liquid hydrogen used at today's chamber pressures produces specific impulses of around 425 seconds. If fluorine were used with liquid hydrogen, the combination should reach about 450 seconds.



Program Status

Liquid engines are used for space work today primarily because of their higher specific impulses as compared to solids, and because historically they happen to be further along in development when our nation started into space. Today the trend is still toward bigger boosters for bigger payloads. The first in such a series of larger liquid boosters is the SATURN I. It uses a cluster of eight liquid engines to develop a total thrust of 1.5 million pounds. The gimbaling of four engines provides directional control. The SATURN I test series has been completed with 10 highly successful firings.

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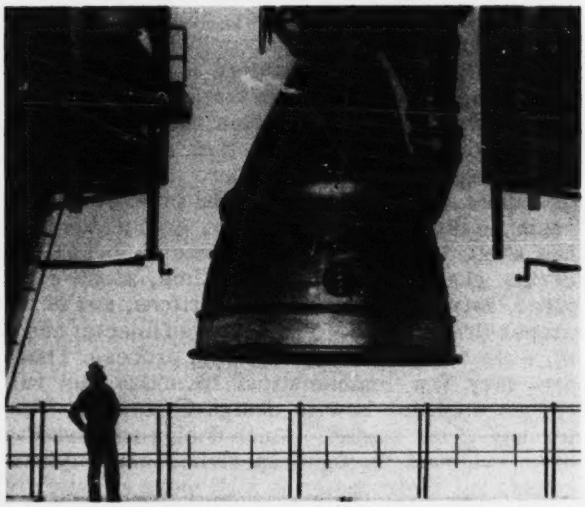
The next step will test the Rocketdyne F -1 engine which develops 1.5 million pounds of thrust in a cluster of five engines to provide 7.5 million pounds of thrust for the SATURN-5 booster. The F-1 has been successfully tested many times in a test stand, but has not been flown as yet.

The turbopump for the F-1 develops 80,000 h.p. and delivers propellants to the engine at a fantastic rate. In a 2-1/2 minute firing, this pump will furnish the five engines that lift our APOLLO astronauts from Earth with 60 railroad tank cars of propellant.



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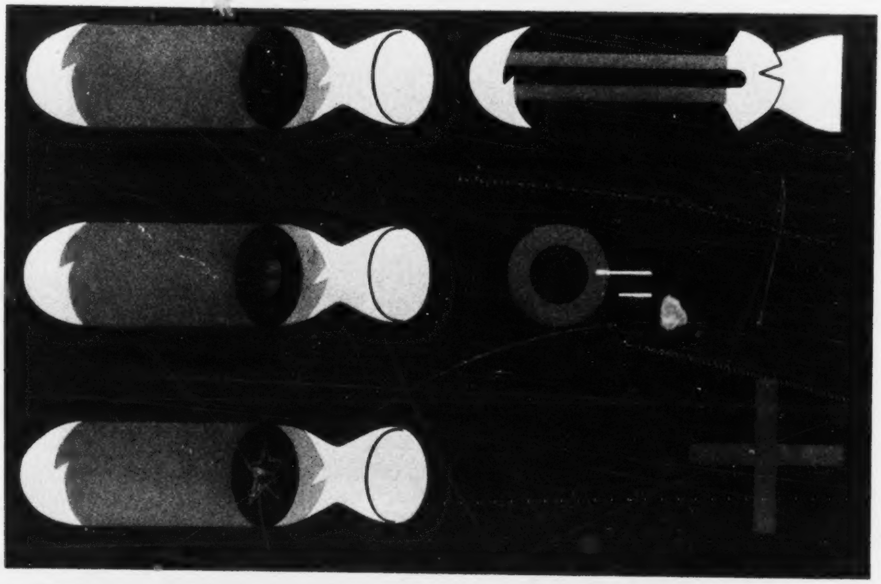
Solid Propellant Rockets

The requirements for a combustion chamber, "nozzle" and a high temperature for exhaust gases are the same for solid propellant rockets as for the liquid propellant rocket. The solid propellant rocket has an advantage over liquids, however, in that no plumbing, pumps, or injectors are required. Solid propellant rockets have long been favored and used in a military environment due to their simplicity, short reaction time (no long countdown), ease of handling, and simple storage requirements.

A solid propellant grain consists of fuel and oxidizer which are mixed together and cast into the desired shape. The casting of the grain is a very delicate process since minute cracks or other defects can cause the burning rate to become explosively high. In this case the performance of the vehicle becomes difficult to control, and engine destruction usually follows.

SOLID PROPELLANT ROCKET



Both the amount of thrust and the burning time can be determined by the physical characteristics of the propellant and the geometrical shape of the grain. The simplest burning technique is the end burning (as a cigarette), but this gives rise to serious chamber insulation problems. Providing a central open core area (as a tube) for combustion permits increasing thrust level as more area is burned. Star-shaped core provided a constant thrust level, since, by their design, the same area is exposed to burning at all times.

There are many different fuels that can be combined with oxidizers and used in solid rockets. Some are heterogeneous mixtures of several chemicals, for example, a mixture of oxidizing crystals such as ammonium perchlorate, with a fuel of synthetic material such as polyurethane. Or, one may use a homogeneous charge of special chemicals such as a modified nitrocellulose type of gunpowder. The specific impulse of solids trends to be relatively low, roughly 265 seconds. This is primarily due to the high molecular weight of the exhaust gases.

The casing of a solid rocket must not only be strong enough to withstand the high pressures generated, but it is also desirable to have the casing light to increase payload capacity. The use of reinforced fiberglass casings has been proven feasible. For example, the A-2 version of the POLARIS missile was able to exceed its design range by 100 miles by the use of these lighter casings.

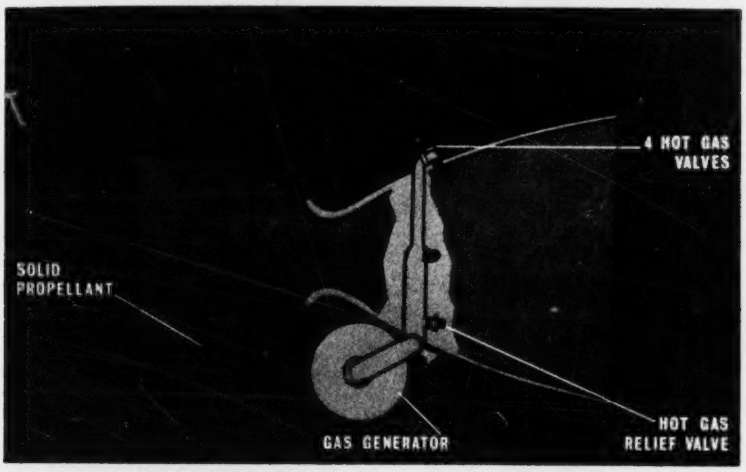
One critical design problem in solid propellant rockets is the control of thrust direction. Since the fuel is burned in its own container, which is often huge, it isn't feasible to move the entire engine structure. There are, however, several other ways of controlling the thrust vector at the nozzle itself besides gimbaling the entire engine.

The POLARIS missiles have used jetavators for thrust control. Jetavators are rings mounted around the nozzle exit which can be tilted into the exhaust stream to deflect the thrust. It takes a deflection of 25 degrees of the jetavators to change the thrust vector by 8 degrees. Some thrust is lost in this process. But it does work, as evidenced by the pin-point accuracy of POLARIS missiles.

Another control is the swivel nozzle - that is, the entire nozzle tilts for control.

Problems may arise here since a higher torque is required for movement of the entire nozzle and pressure seals of the joint at the nozzle are difficult. There is no appreciable thrust loss by the method.

A third approach is the rotatable nozzle, which retains the advantage of full thrust yet requires relatively low torque for movement. In the central neutral position the thrust vector is aligned with the vehicle axis. Movement of the nozzle to any off-center position will cause a thrust vector change.



Other methods of control have been proposed that do not require physical movement of the nozzle. One is the gas injection method which bleeds off exhaust gases at the nozzle throat and then allows them to reenter the nozzle downstream. This changes the thrust vector by destroying the laminar flow of gases through the nozzle, thereby creating a secondary shock wave in the exhaust stream which partially redirects the thrust flow.

Another technique calls for the injection of a liquid into the exhaust stream in the nozzle. The liquid causes a change in thrust vector in much the same manner as in the gas injection method, but the valving and control processes are simplified. The TITAN IIIC is controlled by injections of liquid nitrogen tetroxide.

A further control required with solid rockets is thrust termination to achieve the desired final velocity. Solids cannot be shutdown by valving as in liquids, therefore, a different method of thrust termination is required. One method used is called fore-end venting. In the POLARIS, a series of six ports are simultaneously open in the forward wall of the chamber. Since the total areas of the ports are made greater than the opening of the nozzle, a negative thrust is created to terminate the forward thrust. This negative thrust can be used to separate the booster from the payload.

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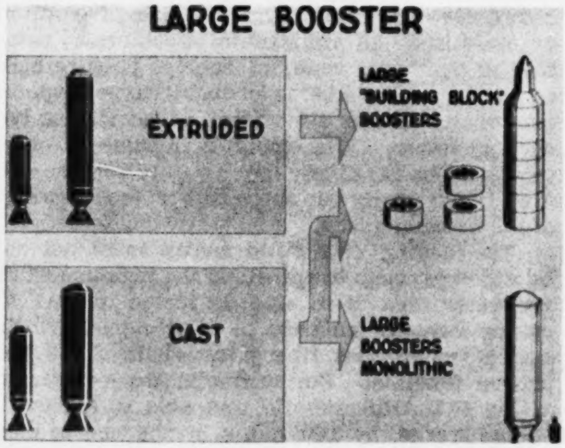
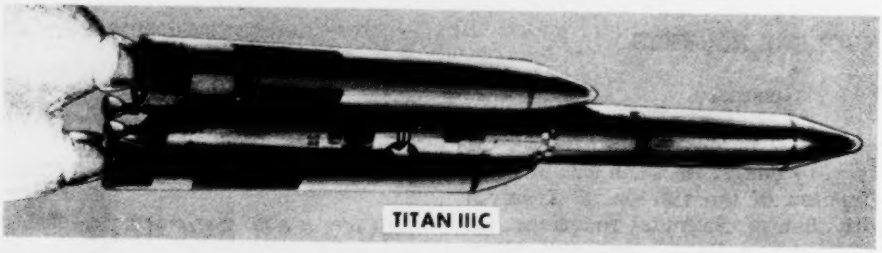
There are many production problems associated with the fabrication of large solid rocket motors, particularly in the handling of the gigantic grains. Motors that are 22 feet in diamter, developing 3.5 million pounds of thrust, have been fired. Development work is in progress on solid propellant rockets that will generate 7.5 million pounds. Obviously these large firecrackers need special handling. Two approaches have been followed in the handling problem: making the motor in one piece (monolithic), or making the motor out of segments or sections. Both methods require stringent handling procedures. The segmented booster is easier to handle but there are some difficulties in mating the segments properly. If the joint is not perfect the effect is similar to that of a cracked grain of propellant, which can detonate upon ignition.





Although the initial funding of solid propellant research for space-flights has been much lower than that of liquid systems, solid propellants may eventually see considerable use as first-stage boosters. The TITAN IIIC uses strap-on solid propellant engines for the boost stage. Its many successes prove conclusively the practicality of solid propellant rocket engines for space flights.

Next Generation

Completion of the development of the 260-inch solid propellant engine would result in over 7 million pounds of thrust in a one-stage engine. Of course, smaller solid propellant rockets will continue to be used in applications requiring dependability and quick reaction time where the lower specific impulse is acceptable, for example, military air launched missiles and certain thrust control engines.

Looking into the future, we can expect interesting developments in the use of air augmentation within the atmosphere to improve solid booster performance. Some experimentation is in progress on the use of ambient air for thrust vector control of boosters. The use of a variable throat area as a throttle for solid propellant rockets may be a breakthrough that will permit shutdown and restart of a space engine.

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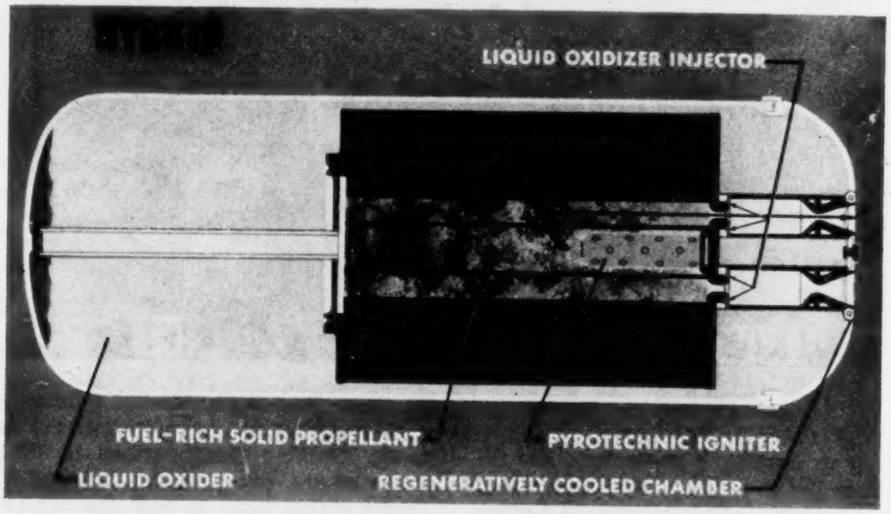


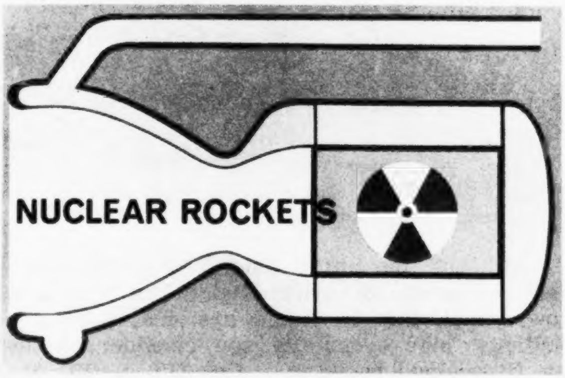
Hybrid Rockets

This discussion of the chemical rocket systems would be incomplete without a brief mention of the hybrid rocket system. These systems use both liquid and solids - usually a liquid oxidizer and a solid fuel. A hybrid rocket possesses some advantages in that it is throttleable, restartable, relatively safe, and should have good performance characteristics. However, it possesses the problems of both liquids and solids with no clear cut major advantage. Development work, at a comparative low level of effort, is continuing in this field.

NUCLEAR ROCKETS

General

The employment of nuclear power for rocket engines appears very desirable when we compare the specific impulse of the fission of Uranium 235 (U-235) with that of chemical reactions. On a pound-for-pound basis U-235 produces about two million times the thermal energy of chemical reactions. Although a nuclear rocket produces a significantly higher specific impulse it also has a much lower thrust-to-weight ratio (about unity) than chemical rockets (about ten-to-one). Any nuclear rocket would be under severe strain to lift itself and a payload into orbit. Another limitation on use of a nuclear rocket as a booster is the radiation hazard produced by an unshielded reactor at ground level and within the atmosphere.



Even though the nuclear rocket is not particularly well suited for ground launch, it has great potential as a means of propulsion in space for lunar or interplanetary travel.

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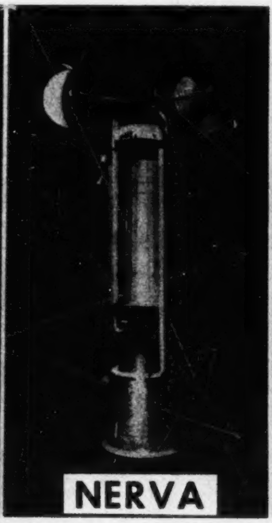
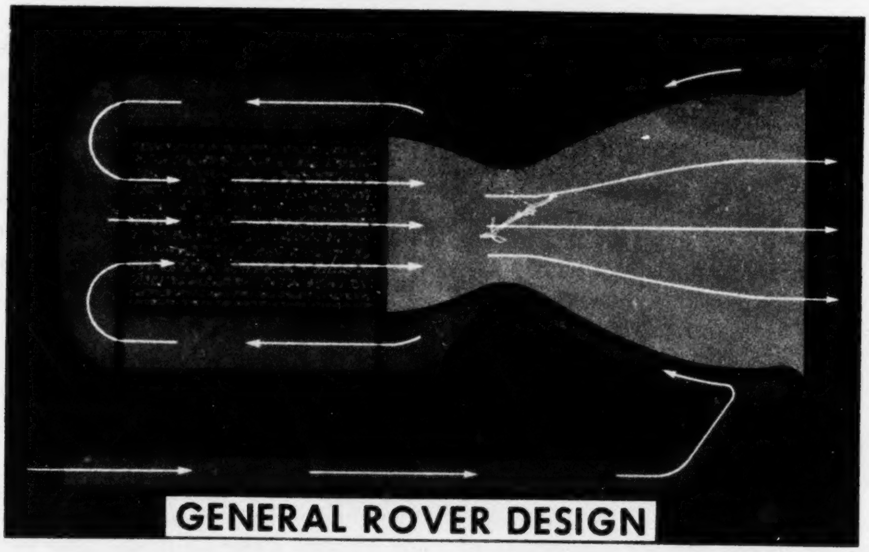
KIWI


NERVA

RIFT

Rover

The program to develop a nuclear rocket for extended missions began in 1955, two years before Sputnik. This program, called ROVER, is divided into three phases: The first phase, assigned to scientists at Los Alamos, was to test the principles of nuclear rockets in a series of non-flying reactors. This design phase was appropriately named KIWI, after the small wingless bird native to New Zealand. The second phase was to turn the experimental reactor into a flyable engine. The contract for this engine, called NERVA (Nuclear Engine for Rocket Vehicle Application), was awarded to Aerojet-General and Westinghouse Electric Corporations in 1961. The final phase of the program, called RIFT (Reactor in Flight Test) was to test the NERVA engine in flight. A contract for RIFT was signed in May 1962 with Lockheed Missiles and Space Company. The first phase of the program, KIWI, has been completed for the smaller-size reactors, and the second phase, NERVA, is well underway. The third phase of the program, RIFT, has been postponed indefinitely by program redirections announced in December 1963.



GENERAL ROVER DESIGN

Design Problems

All of the rockets which have been built as a part of ROVER follow the general design of the illustration. Liquid hydrogen is the usual propellant. The propellant also serves as a coolant for the engine structures by entering through cooling passages in the outer walls of the exhaust nozzle, then passing through the jacket of the engine into the core of the reactor. The propellant is heated by the reactor to a temperature of about 4000°F and then expands through the exhaust nozzle to produce rocket thrust.

The design of nuclear rocket reactors starts with the need for high temperatures—indeed, the highest temperatures that can be practicably obtained. Such high temperatures preclude reactor cores made solely of uranium or its compounds, because their melting points are too low. A core, then, must be made of some matrix material with a high melting point in which the fissile fuel, U-235, is incorporated. There are only a few candidates from which to choose for this matrix material: graphite, tungsten, and the carbides of zirconium, niobium, hafnium, and tantalum. The carbides of zirconium, hafnium, tantalum and, to a lesser extent, niobium are neutron absorbers. This does not completely rule them out, but their use would make reactor design much more difficult.

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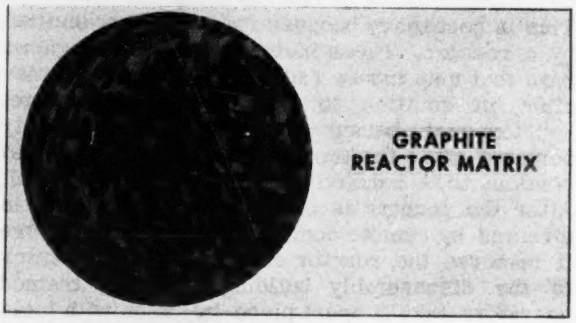
Of the remaining two materials, graphite is by far more appealing than tungsten. Graphite has been used in industry as a high-temperature material for years; it is cheap, readily available, and easily machinable. And because it is not a strong neutron absorber, it lends itself admirably to a particularly simple reactor concept, that of the homogeneous, solid-core reactor. In a homogeneous reactor, the uranium fuel is distributed evenly throughout the reactor core rather than concentrated in a few rods or blocks. In the uranium-graphite matrix, graphite also acts beneficially to moderate, or slow down, neutrons. Slow neutrons are intrinsically more effective than fast neutrons in causing fission of U-235. Therefore less U-235 is needed in the reactor. The graphite also provides structural integrity to the reactor matrix, and is in fact the material by which most of the heat energy resulting from fission is transferred to the propellant.



GRAPHITE REACTOR MATRIX

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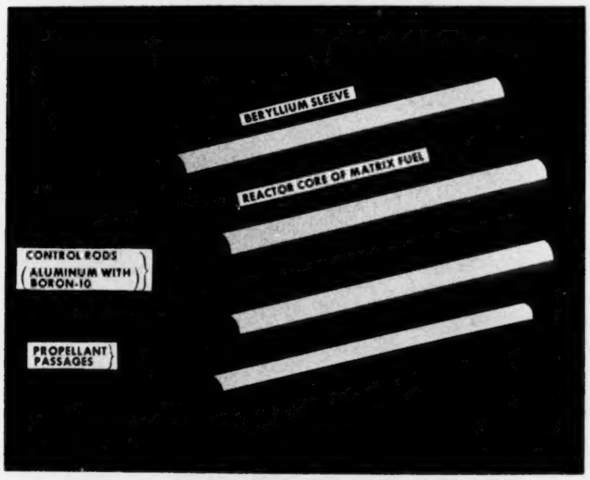
BERYLLIUM SLEEVE
REACTOR CORE OF MATRIX FUEL
CONTROL RODS (ALUMINUM WITH BORON-10)
PROPELLANT PASSAGES

The core of the rocket reactor consists of an assembly of matrix fuel elements, suitably supported. Numerous passages, which are lined to prevent corrosion, carry the propellant through the fuel matrix. Surrounding the core is a cylindrical reflector sleeve of beryllium. The beryllium sleeve serves two functions: (1) it serves as a reflector material which, because of its low atomic mass, causes neutrons that penetrate it to rebound back into the core, and (2) it provides a convenient location for the insertion of control rods made with a material that strongly absorbs neutrons. With the proper physical placement the neutron absorbers are able to offset the reflective properties of the beryllium sleeve and reduce the neutron flux to below criticality, which in turn results in reactor shut-down.

In a rocket reactor, the typical control rod consists of a beryllium cylinder, one side of which is covered with an aluminum sheet heavily loaded with an isotope, Boron-10, that strongly absorbs neutrons. By rotating the control rods, the sheet with Boron-10 can be brought nearer the reactor core where it absorbs many neutrons, or rotated away from the core where it absorbs fewer neutrons. The control rods are placed in the reflector rather than in the core proper because it is easier to cool the reflector, which simplifies structural design of the reactor.

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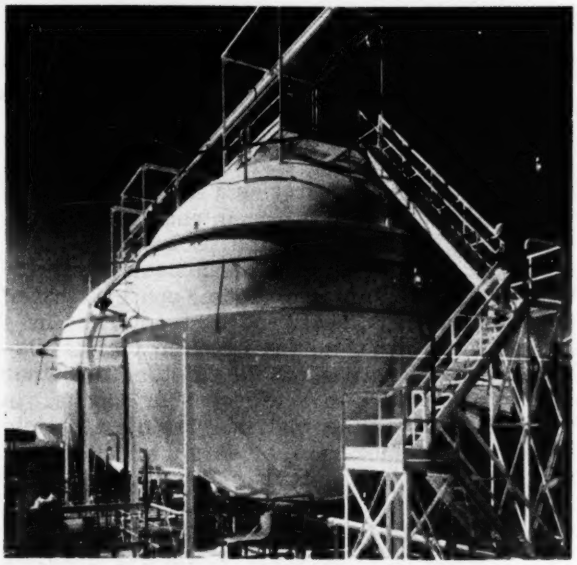
Test Problems

The problems of testing a nuclear rocket are almost as difficult as the design problems. Because of the large appetite of a reactor for propellant, the Los Alamos Scientific Laboratory (LASL) built two 55,000 gallon dewars for storing liquid hydrogen on the test site at Jackass Flats, Nevada. Yet even these giant vacuum bottles contain only enough liquid hydrogen for an 8-minute run of a reactor at a power setting of one thousand (1000) megawatts (nearly the energy output of monstrous Hoover Dam)!

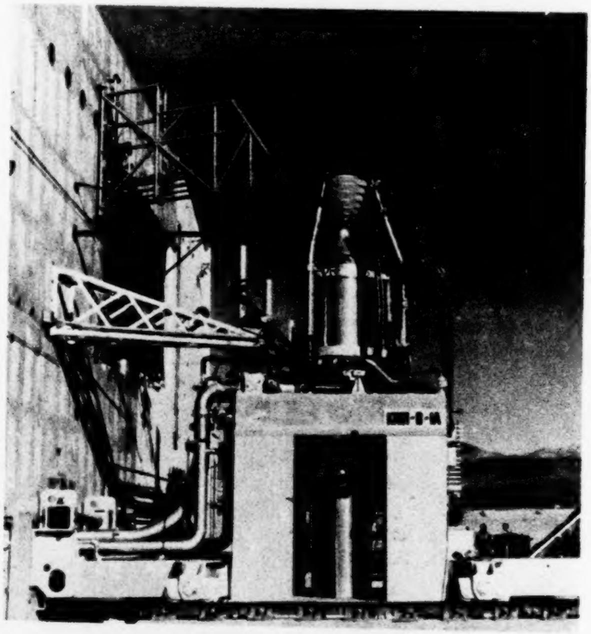
As a further complication, all of the reactor tests must be conducted by remote control from a command building protected from the test cell. This is necessary because radiations are emitted by a reactor. These include neutrons and gmma rays that may induce radioctivity in nearby materials in addition to causing direct damage.

Moreover, because some of this radioactivity remains after the test, the tested reactor must continue to be handled entirely by remote control. After the reactor is shut down, a locomotive is directed by remote control to the test cell where it removes the reactor on a standard gage track to the disassembly building. There, trained operators take it apart piece-by-piece with tools held in giant robot-like manipulators. The information gleaned from such examinations has proven worthwhile and pointed the way to many structural improvements.



KIWI

The first reactors built as a part of the ROVER program were the KIWI-A reactors designed for a yield of one hundred (100) megawatts. By 1960 LASL had designed, built, and tested three of these, and in so doing, had learned a good deal about the fundamentals of uranium-graphite reactors. In the last two KIWI-A tests, however, the reactor core experienced some structural failures. As a result, LASL investigated three different reactor core designs for the next generation of KIWI reactors. The generic name for these new one thousand (1000) megawatt reactors was KIWI-B. The three designs were labeled B-1, B-2, and B-4 (B-3 never got off the drawing board). Many of the over-all features of the reactor design were successfully proven in December, 1961 when KIWI-B-1B was tested at 300 megawatts with gaseous hydrogen. The first run with liquid hydrogen occurred in September, 1962. Although this test with liquid hydrogen was a successful milestone in the ROVER program, it found that the core design was unsound.



At that time, LASL was pinning its hopes primarily on just one of the three new designs, that of KIWI-B-4. But when the B-4 design was tested in late 1962 there was a sharp program setback. The test uncovered a flow-induced dynamic instability that vibrated the individual fuel elements so violently that some of them were broken and propellant passages were ruptured.

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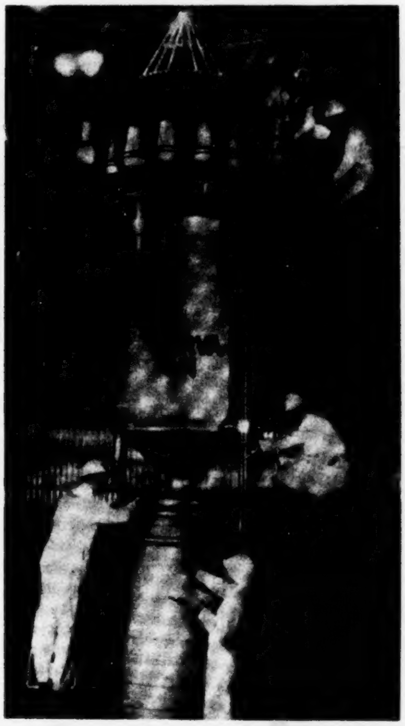
A completely redesigned B-4 reactor was tested only 18 months later in May of 1964. It proved to be a resounding success (even though the run was curtailed somewhat because of a minor failure in the nozzle). In August 1964, the KIWI-B-4E ran essentially at full power and temperature for 8 minutes. This same engine was run again two weeks later for an additional 2 1/2 minutes, thus demonstrating that a re-start was feasible. LASL was able to control the power, temperatures, and flow rates on the second run so that it successfully duplicated the conditions of the first test. Disassembly indicated that the reactor could have run even longer without trouble. There was, as expected, evidence of graphite corrosion, but nothing was uncovered to prevent the development of reactors having useful burn times of 30 minutes or more.

All in all, the KIWI-B-4E tests were as successful as anyone dared to imagine a test could be.



NERVA

At the same time that design test programs were reaching their goals, the Aerojet-Westinghouse team had been proceeding with the NERVA Project whose objective was to develop a flyable engine based upon the successful KIWI-B-4E reactor. The development of an engine from a reactor is a difficult project. For one thing, structural changes were needed in and near the reactor proper for the high "g" loadings expected. Furthermore, a light weight turbopump system which could operate in the radiation field of the reactor had to be developed, and radiation shielding between the reactor, the hydrogen storage tanks, and payload structures had to be incorporated. Numerous flight controls and a flight nozzle also had to be developed. All of these components must then be integrated into a compact, flyable package.

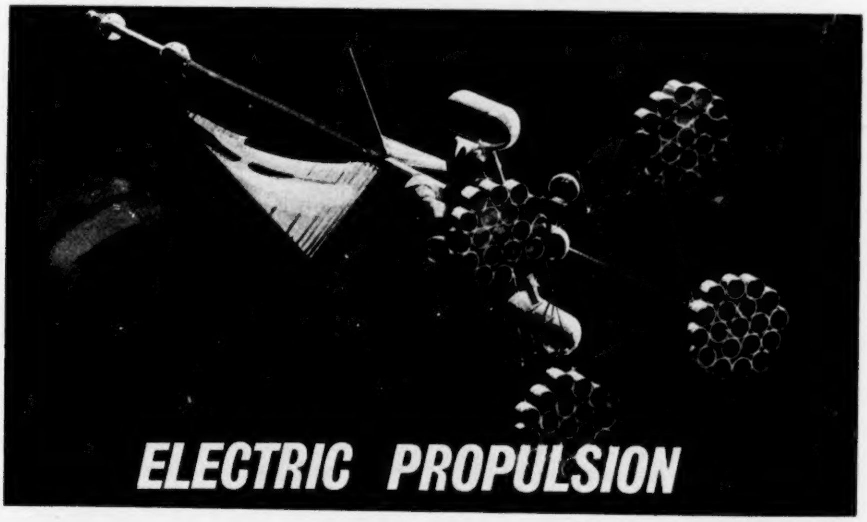
In October of 1964 shortly after the last of the KIWI tests, the NERVA team tested their first reactor, the NRX-A2 which was a modification of the KIWI-B-4E design. The tests were a complete success; the reactor ran at substantial power for 5 minutes and reached a peak-power close to 1100 megawatts for 40 seconds. (This engine would produce about 55,000 pounds of thrust). One restart was made of the NRX-A2. In May 1965 another NERVA reactor, NRX-A3, ran successfully for more than 16 minutes at full power with two restarts. In June, 1966 the NRX-A5 tested successfully with two restarts and thirty minutes of run at full power. It was clear that the ROVER program had produced a good basic design for a flyable rocket engine.

Rift

From a technical standpoint it appears that a nuclear rocket could be developed and tested by 1971. During the next few years, Aerojet and Westinghouse will carry out further experiments whose results should be applicable to engines of the future, even though reactor sizes and principles may change. It appears that the KIWI-B-4E reactor may never be developed into a flight engine, primarily because its thrust is somewhat low for many proposed interplanetary missions. One alternative, which has had its advocates, would have been to uprate the KIWI-B-4E reactor to 2000 or even 25,000 megawatts. This might conceivably have been done by increasing the propellant pressure and flow rates. A somewhat more popular approach now is to concentrate on the new PHOEBUS project which is the name for a new family of reactors of greater power. PHOEBUS-1-B was successfully tested at full power (1500 megawatts) for 30 minutes in Nevada on February 23, 1967. PHOEBUS-2, a new five thousand (5000) megawatt reactor is under development by LASL.

Future

The PHOEBUS-2 is undergoing a development program similar to the KIWI program for the smaller reactors. When this larger reactor is developed, it will become the basis for a practical, flyable rocket engine. The large NERVA rocket may then be used as a third stage in the Saturn V rocket, now planned for the APOLLO Program and future interplanetary programs. Such a nuclear third stage will have a power rating of 5,000 megawatts. Converting this power rating to effective boosting power indicates such a nuclear third stage would provide between 200,000 and 250,000 lbs. of thrust for at least thirty minutes. The efficient use of fuel (825 seconds specific impulse) could lead to an increase in useful payload of almost 100% over the chemical third stage of the present Saturn V vehicle. It appears inevitable that man will soon use nuclear rockets to aid him in the investigation of the far reaches of our solar system.



ELECTRIC ROCKETS

General

It has been pointed out earlier that a chemical rocket has a high thrust-to-weight ratio which allows it to push heavy payloads into space, especially into Earth orbits. Such short trips can be accomplished adequately with the thrust and the specific impulses of current chemical rockets. However a mission into deep space might be better accomplished with an engine using fuel more economically than current methods of chemical combustion.

The Mars Mission, for instance, could be accomplished with greater overall fuel economy with an engine providing a specific impulse of 7000-9000 seconds. If we should plan to use only chemical rockets to send large spacecraft to Mars and beyond, we will require either extremely large launch vehicles for a direct trip, or we must place several vehicles into Earth orbit for prior rendezvous and assembly. Both of these methods are expensive in weight of propellant and vehicles required. To conduct deep space missions more efficiently, we must develop a propulsion system that uses fuel more economically than chemical engines.

We have discussed nuclear rockets as a step toward greater specific impulses and fuel economies. Now we shall consider electric rockets for space flights since electric engines do use fuel more economically than either chemical or nuclear rockets. Fuel economy of a rocket engine is indicated by its specific impulse, which is the total impulse generated per pound of fuel used. The higher the specific impulse of a fuel, the longer is the time period over which one pound of fuel will deliver one pound of thrust. For convenience, specific impulse is expressed in seconds.

Chemical rockets may produce specific impulses to about 450 seconds, but relatively little improvement can be expected since the energy liberated is limited by heats of combustion of the fuel. Solid-core nuclear rockets can deliver specific impulses up to about 1000 seconds but are limited by heat exchange mechanisms as well as radiation and structural limits. Electric engines which include a generating source of electrical power however, are now operating in vacuum chambers at specific impulses of 800 to 10,000 seconds and higher. Electric engines therefore do produce high fuel economy, but unfortunately as the specific impulse increases for a given thrust, the electrical power needs and power plant weights also increase. A crossover point of diminishing returns must be determined for each specific mission, or, saying it in another way, an engine to provide the optimum total impulse must be selected for each specific mission. (Total impulse is thrust multiplied by the time it is applied. A million pounds of thrust applied for 30 seconds will deliver 30,000,000 pound-seconds of "total impulse." One pound of thrust applied for 30,000,000 seconds, which is roughly a year, will provide the equivalent total impulse.)

Each flight in space requires a certain total impulse. Assuredly the total time duration of the mission must also be considered in the choice of the optimum total impulse. The goal of deep space propulsion is to carry the least amount of fuel and engine weight for a given total impulse. However, we should recognize that using an engine with too much specific impulse might be as uneconomical as using an engine with too little specific impulse. The Mars Mission, for optimum fuel use, requires an engine with 7000-9000 seconds of specific impulse. Therefore an engine with 7000-9000 seconds of specific impulse should be selected since engines with either higher or lower specific impulses would be less efficient. Electric Rockets with specific impulses in this range appear available in the foreseeable future.

In addition to improvements in the specific impulse of rockets we should also consider the importance of increasing the exhaust velocities of rocket engines for long range space flights. The importance of the exhaust velocity, C, is immediately apparent when one recalls the basic rocket equation:

$$V = C \ln\left(\frac{M_0}{M}\right) = I_{sp} \quad g \ln\left(\frac{M_0}{M}\right)$$

Where V = change in velocity achieved in free space acceleration.
C = exhaust velocity of the rocket.
M_0 = initial mass of the rocket.
M = final mass of the rocket.
I_{sp} = specific impulse.
g = acceleration of gravity.

Higher velocity increments can be obtained by increasing the mass ratio, for example, by staging the boosters and discarding structures such as empty tankage or nonvital subsystems whenever appropriate. However these improvements are limited by the logarithmic nature of the mass ratio term and the requirement to retain payload structures and functional engine parts such as nozzles and pumps.

One can improve over chemical rockets in a direct manner if the exhaust velocity is increased by providing more energy to the propellant. Nuclear rockets use the heat of their reactors to increase the exhaust velocity of a light gas, hydrogen, to about 2 1/2 times that obtainable in chemical engines. Therefore nuclear rockets will use propellant weight about 2 1/2 times as effectively as chemical rockets. Another approach to increase exhaust velocity is to use electrical energy to accelerate the propellant gas up to 20 or more times the velocity that is obtainable in chemical rockets. These high exhaust velocities obtained in the electric engine increase its specific impulse to about 20 times that of chemical engines. With such high fuel effectiveness, and with its capability to apply continuous thrust, the electric engine is a promising candidate for space propulsion. Despite its low thrust-to-weight ratio which completely precludes its use as a launch rocket, the electrical engine can be boosted into space by other rockets and then started for long term propulsion chores.

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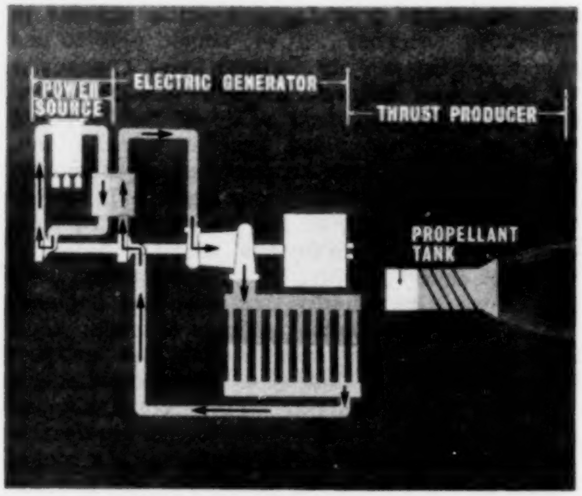
Electric Rockets

An electric rocket consists of: (1) the power source, (2) the electric generator, (3) the thruster mechanism to produce directed acceleration of the propellant, and (4) the propellant.

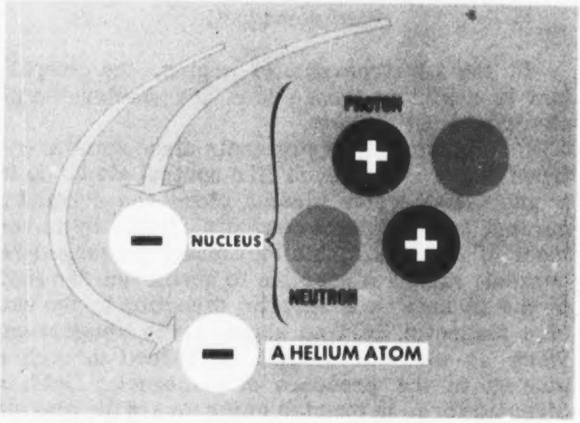
Since the type of thruster mechanism employed is the principal distinction among electric rocket engines, let us consider three basic thruster mechanisms which are designated by types as (a) electrothermal, (b) electromagnetic, and (c) electrostatic. An electrothermal engine uses energy from an electric power supply to heat a gas; an electromagnetic engine uses electromagnetic fields to accelerate ions; and an electrostatic engine uses a high voltage electric field to accelerate ions.

Before going further, there are two basic terms which should be defined: they are ionization and plasma.



Currently the atom is depicted as a massive nucleus surrounded by electrons. The nucleus consists primarily of protons and neutrons. A neutron has no charge associated with it, a proton has one positive charge, and an electron has one negative charge. Where the same number of negative electrons "orbit" as protons in the nucleus, the atom is electrically neutral.

If one or more of these electrons are removed from an atom, there is an excess of positive charge in the atom, or, in other words, a positively-charged ion has been created. The atom has become ionized. A plasma is a large group or cloud of ionized atoms with, or without, their dissociated electrons. A plasma may be positive, neutral, or rarely, negative.



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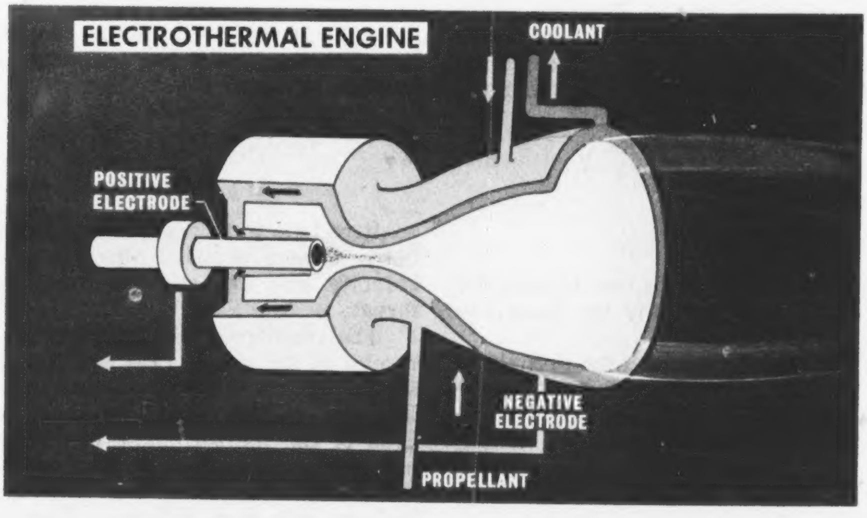


Electrothermal

In the electrothermal engine, electric energy is used to heat the propellant to a high temperature. This heating may be accomplished by passing the propellant gas through an electric arc or over surfaces heated with electrical power.

The electrothermal rocket is similar in some respects to the chemical rocket. Although there is no fuel combustion, the propellant gas is heated to a high temperature and expands through a nozzle to produce thrust. We can achieve exhaust velocities higher than those of chemical engines if the energy added to the gas is greater than the energy added in chemical combustion. One limit to the amount of energy given to the propellant is the breaking up or dissociation of the propellant molecules. Such breaking up absorbs energy without raising the gas temperature. Factors which limit the exhaust velocity include the occurrence of turbulent flow regions caused by erosion near the arc, and other material failures.

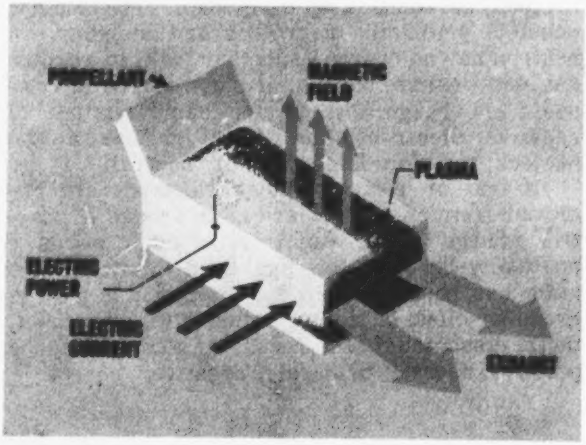
The electrothermal rocket is in a fairly advanced state of development, and has reached efficiencies of about forty percent (40%). Because greater exhaust velocities have been limited by material failures, the electrothermal rocket probably will not be used for deep space flights requiring long engine burn times. Electrothermal engines can be, and are, used as short burn thrusters for satellite station keeping and orbit adjustments.

Electromagnetic

In the electromagnetic engine, the propellant is a plasma whose ions are accelerated by electromagnetic fields.

In a plasma, ions with their dissociated electrons swirl about much like neutral atoms do in a gas cloud. This plasma cloud can conduct a current just as a wire conducts current by movement of charges. This movement of charge (the current) makes it possible to accelerate the ions of the plasma in a specific direction by the use of a magnetic field as shown in the illustration. When an electric current is forced through a plasma in the presence of a magnetic field, a directed force is exerted on the ions of the plasma which accelerates them rearward at very high velocities. This is similar to the force on a rotor in a simple electric motor.

However, a plasma engine is quite complicated, and all of the physical occurances in it are not yet fully understood. Nevertheless the plasma engine has great promise of becoming a workable electromagnetic engine. Research is continuing on it for purposes of space propulsion.



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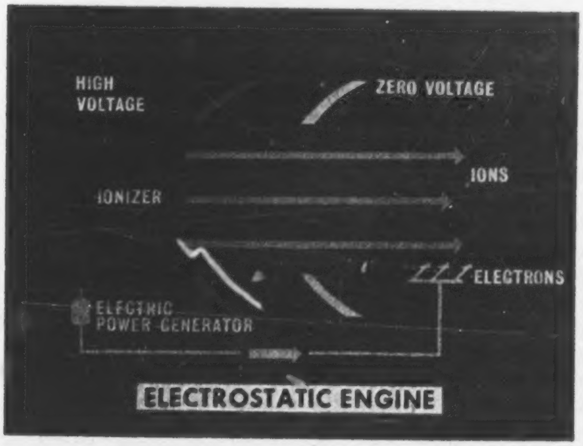
Electrostatic

The last type of engine to be considered, the electrostatic engine, is probably the most advanced of the electrical rockets.

Just as in the plasma engine, the propellant is ionized by removing electrons. In the electrostatic engine, however, the electrons are entirely removed from the ionization region leaving positive ions to be accelerated by a static electric field. These positive ions reach a high exhaust velocity and are ejected rearward to produce thrust.

The electrons are removed from the ionizer region at the same rate that they are produced. If the excess electrons were not removed, a negative charge would build up on the surface area of the ionizer and prevent the formation of new ions. Therefore it is necessary to remove these electrons from this area to maintain the ionizer at a high voltage. Electrical power is required to remove these electrons since they would normally remain in a region of high positive voltage. To prevent this from occuring, an electron pump pulls electrons away from the ionizer region and permits ionization of the incoming propellant atoms.

These withdrawn electrons are beneficially used to neutralize positive charges in the ion exhaust stream. If the exhaust stream were not so neutralized, the ions in it would repel one another, the exhaust stream would become turbulent and the engine would lose thrust. Furthermore, without neutralization, the spacecraft would become negatively charged to such an extent that the discharged positive ions would be attracted back to it resulting in loss of thrust.



Program Status

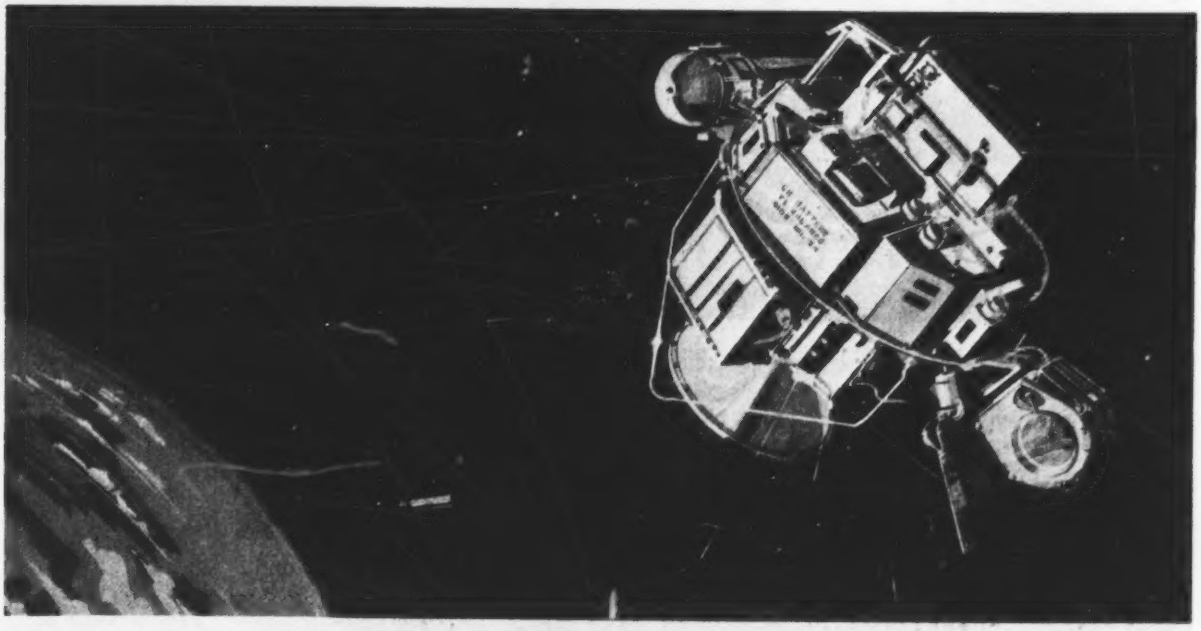
Electrostatic rockets are well advanced in research and development. On July 20th 1964, two of these type rockets were tested in space. One rocket used mercury for a propellant and the other used cesium. Both of these metals ionize easily (they possess low work functions). Both engines were mounted in the NASA SERT-1 vehicle. SERT stands for Space Electric Rocket Test. SERT-1 was launched by a Scout rocket into a ballistic trajectory for fifty minutes of flight.

The primary purpose of SERT-1 was to test the performance of electrostatic rockets in space. These engines had successfully run for hundreds of hours in a vacuum, but space operations are not completely simulated by a vacuum chamber. For instance, the cesium or mercury ions from the engine may strike the walls of the vacuum tank and knock secondary electrons loose from the walls. Under such conditions it is difficult to determine if the electrons from the engine were totally successful in neutralizing the positive beam, or if secondary electrons from the walls of the chamber corrupted the data. Since these electric engines developed only small thrust, the 50-minute ballistic flight would not have been long enough for the engine thrust to propel or accelerate the SERT-1 vehicle a noticable amount. Therefore the electrostatic rockets were mounted tangentially so that the thrust developed would spin the spacecraft. Even a small thrust could then be measured by observing any change in the rate of spin of the spacecraft. The engine using mercury aboard the SERT-1 flight worked as expected, but the cesium engine failed to operate properly because of a breakdown in the high voltage system.

The Air Force has since tested a cesium engine which operated successfully. SERT tests are continuing. The flight of SERT-2 is planned for late 1968 or early 1969. SERT-2 will use an Agena vehicle and carry two 6-millipound thrusters. The power source will be a large 1.0 kilowatt array of solar cells. This second launch will demonstrate the longevity of an electrical propulsion system in space.

Next Generation

Electric engines will have to operate continuously for months or even years. Therefore, it is necessary to have a high degree of reliability to insure that the vehicles will survive to reach distant targets. Journeys to the distant planets will require bigger and better rockets with more thrust than is available from these research and development engines. The development of electric rockets with greater thrust will require more work, time, and money.



Light weight power supplies which provide significant amounts of power must be developed before manned space flight with electric propulsion will be feasible. Nuclear power supplies offer great promise for manned flight using electric propulsion.

For umanned probes, solar cell technology is very nearly at the state-of-the-art where a marriage between an electric engine and a solar-cell array is possible.

A chemical rocket can lift only 2-3% of its own weight as payload into an Earth orbit. Optimally, second and third stage rockets should take only a small part of this 2-3%. Light, economical rockets such as the electric rockets can be very useful in such conditions. Continuing advances in the development of electrical propulsion techniques will bring us closer to the day when deep space exploration by man will be a routine reality.

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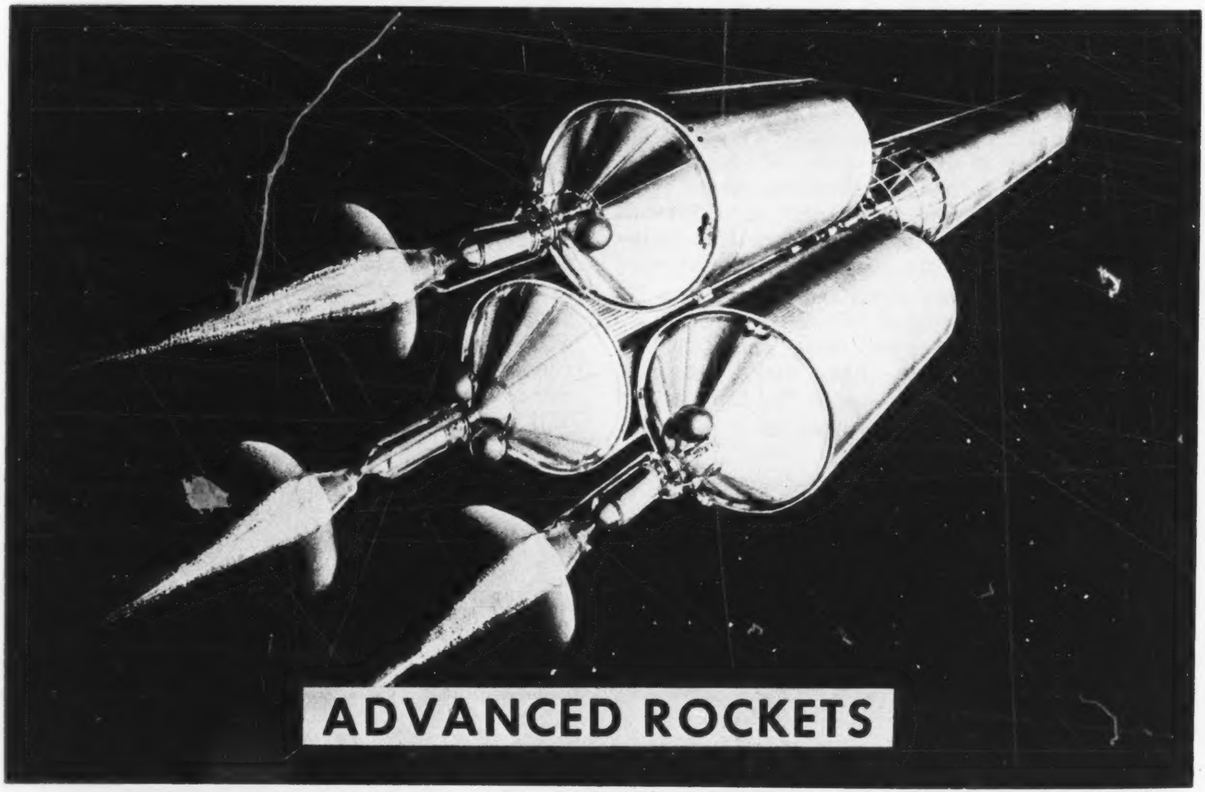


ADVANCED ROCKETS

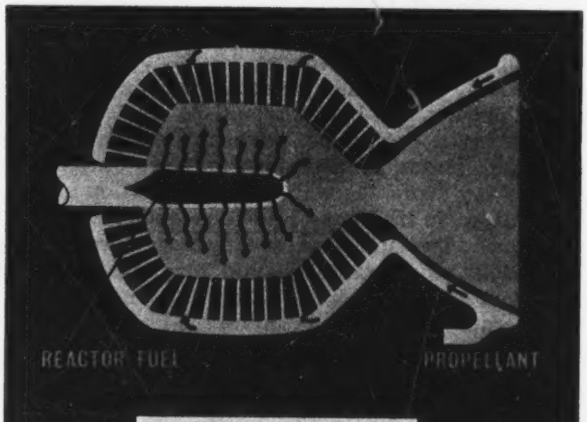
The rocket types already described in earlier sections are either operational or known to be feasible in principle. In contrast, the rockets considered next may not be feasible and the problems involved are still a long way from being solved. Yet, since scientific break-throughs may occur, it may be profitable to explore some concepts for advanced rockets. The five propulsion techniques which have received the attention of authors, such as S. Glasstone in Sourcebook on The Space Sciences, are categorized as:

(1) Cavity Reactors
(2) Nuclear Explosions
(3) Fusion Reactors
(4) Photon Rockets, and
(5) Solar Sailing

Cavity Reactors

Because of the limitations of structural materials to withstand extremely high operating temperatures, it appears that the specific impulse of a nuclear fission rocket with a solid-core will not exceed about 1200 seconds. But if the fission reaction could be sustained in a gaseous cloud without structural support, in what is called a cavity reactor, these temperatures could be several times those possible in a solid-core reactor and might reach 45,000 °F. With hydrogen as the propellant, the specific impulse would then be approximately 3500 seconds. The fissile material (for example, uranium-235 or plutonium-239) would presumably be used in its elemental form since any compounds would be decomposed at the proposed temperatures. Furthermore, because of the high temperature, the uranium or plutonium would be in the form of a gas or vapor. The gas would be at least partly ionized; in other words, it would be in the form of a plasma. The cavity in which heat is produced by fission would be equivalent to the combustion chamber in a chemical rocket. Hydrogen propellant entering the cavity would be heated by direct contact as a result of atomic collisions with the fission products. The hot gas would be expelled through a conventional nozzle, thus producing the required thrust.

As just described, the gas-phase fission reactor has a serious drawback; the fissile material would be expelled continuously with the propellant. The increase in average molecular weight of propellant to impulse would, of course, decrease the specific impulse, but this is a relatively minor matter. Much more serious is the cost of the uranium-235 that would be required for developing and operating such cavity reactors. The current price of uranium-235 in relatively pure form is above $5,000 per pound of contained uranium-235. Another factor is the huge mass of fissile material that would have to be carried in order to run the rocket engine for an appreciable time. This would greatly offset the advantage of the high specific impulse. Some means must, therefore, be found for preventing or minimizing the escape of uranium from the reactor cavity. Several proposals have been made in this connection.



CAVITY REACTOR

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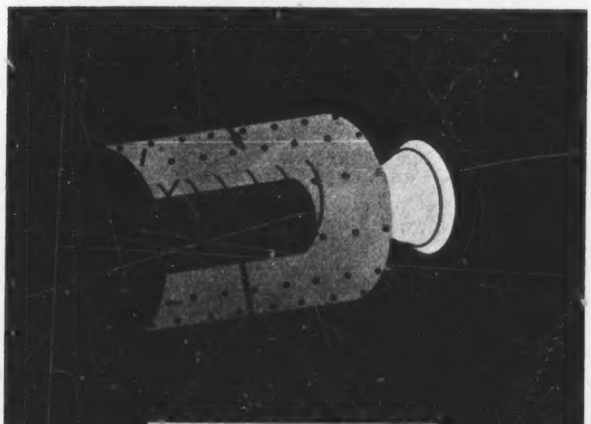
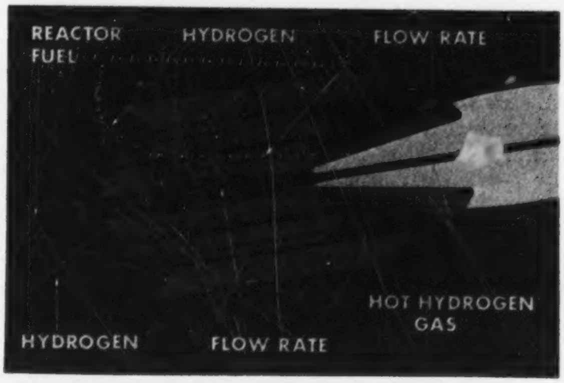
One proposal is the vortex reactor in which advantage would be taken of the large ratio of the masses of the uranium to hydrogen atoms, that is, 235 to 1. The mixture of uranium and hydrogen gases (or vapors) would be introduced into the cavity in a tangential direction. As a result of gas-dynamic action and the centrifugal effect, the heavy uranium atoms would tend to form a hollow cylindrical cloud in which heat is generated by fission. The much lighter hydrogen atoms and molecules would diffuse through the cloud toward the center of the vortex, and the hot gas would be expelled through the nozzle. Laboratory experiments with a mixture of bromine vapor (heavy molecules) and air (light molecules) have shown that some degree of separation can be achieved by the vortex, but the mechanism is much more complex than had been anticipated.



VORTEX REACTOR



A drawback to the foregoing scheme is that the highest temperatures are attained at the outside of the vortex closest to the walls of the chamber. The cooler entering gas may provide some protection, but it would be preferable if the hydrogen propellant were on the outside and the much hotter fissile material were on the inside, away from the walls. This situation might be realized in the coaxial flow concept for a cavity reactor. The uranium and hydrogen would be introduced in separate coaxial streams with the hydrogen surrounding it. By maintaining a much lower rate of flow of uranium than of hydrogen, a stable stream might be realized in which relatively little of the uranium would be expelled through the nozzle. In the coaxial flow reactor, the hydrogen would be heated by radiation from the central fissile core. But below about 10,000°F hydrogen does not absorb thermal (heat) radiation and consequently an opaque, absorbing material (for example, graphite dust) would have to be added. The particles (or atoms) of the absorber would then transfer part of their kinetic energy to the hydrogen by collisions and thereby raise its temperature. Preliminary tests with mixtures of bromine vapor and air indicate that coaxial flow separation has possibilities for development.

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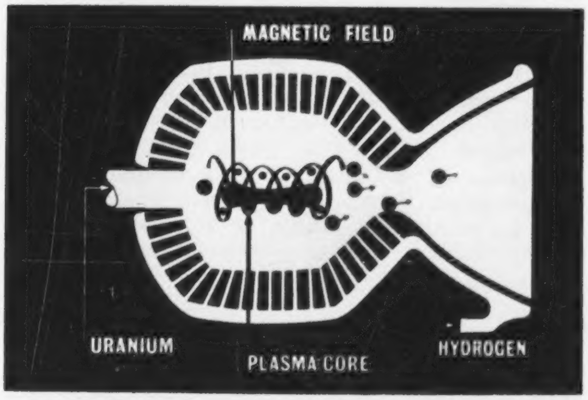

Another proposal for a gaseous core reactor for rocket propulsion is the plasma core concept. At sufficiently high temperatures the fissile material would be in the form of an ionized plasma. Confinement by a magnetic field might then be possible. The hydrogen propellant would then flow around the central plasma core confined in this manner; heat generated by fission in the core would then be transferred to the propellant by radiation, provided a suitable absorber were present. Apart from other problems, there would be difficulties in providing the equipment for generating the strong magnetic fields required to confine the plasma core.

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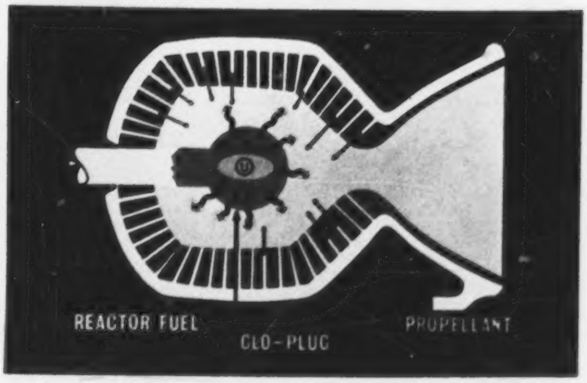
In the "glo-plug" or "light bulb" system, a material wall would be used for keeping the gaseous nuclear fuel and the propellant apart. The uranium-235 constituting the reactor core would be contained in a vessel of a material that can withstand high temperatures, but is transparent to and is not damaged by the various radiations emitted by the nuclei undergoing fission. The propellant flowing outside the containing vessel would then be heated by the radiation from the core. The presence in the propellant of a substance that can absorb these radiations would, of course, be required. The walls of the vessel separating the fissile material from



the propellant could be prevented from becoming excessively hot by utilizing the cold, transparent propellant as a regenerative coolant. Recent research indicates that a wall of fused silica which is cooled by a layer of helium or neon may prove feasible.

It has been assumed that all the gaseous core concepts thus far described use hydrogen as the propellant. In view of the very high temperatures expected, it might be possible to make use of liquid ammonia, which is easier to store, or even of water as the propellant material. The molecules of these compounds would be completely dissociated into their constituent atoms, that is into nitrogen and hydrogen or into oxygen and hydrogen, respectively. The advantage of a cheap, storable propellant might well outweigh the accompanying decrease in specific impulse.

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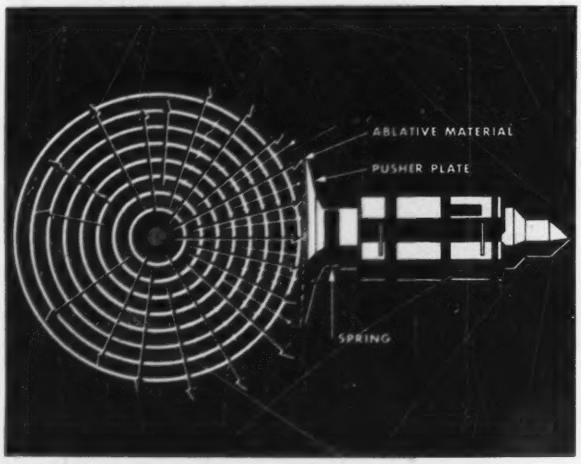
Nuclear Explosions

Let us now look at one entirely different approach to the employment of nuclear energy for rocket propulsion. This technique has been designated Project ORION and uses the explosions of small nuclear bombs to impart motion to a space vehicle. These bombs would be ejected and exploded by the spacecraft at programmed intervals. Because of the health hazard arising from the radio-activity of the fission products, such a mode of propulsion could be used only at some distance from Earth. Under this condition, the air density would be very low and the shock wave, which is normally responsible for much of the destructive action of a nuclear explosion would be of minor consequence. Radiation produced by such explosions present only a small problem in space, and the hazards can be overcome by placing radiation shields to protect any areas of concern.

One way in which the effects of nuclear explosions in space might be realized for propulsion purposes is represented in the nearby diagram. Attached to the space vehicle is a pusher plate of relatively large area, and bombs are exploded at intervals a moderate distance behind the plate. The rapid expansion of the bomb residues would cause fission-product particles to strike the pusher plate at high velocity. As a result of the impact, momentum would be imparted to the spacecraft and its velocity would increase. In this manner, very high velocities might be attained by the successive explosion of a number of atomic bombs. Specific impulses attainable in this manner are estimated to be from 2000 to 3000 seconds.

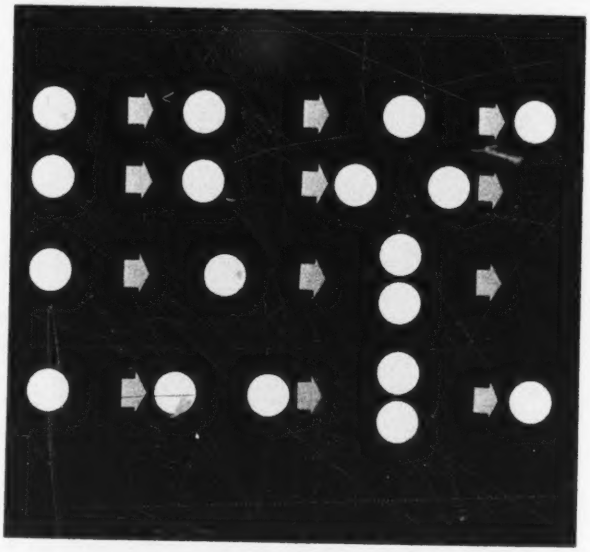
In order to protect the pusher plate from the high temperature accompanying the nuclear explosions, the plate would be coated with an ablative material. Absorption of radiation would heat the material and cause ablation to occur.

Many difficult problems are associated with the concept of propulsion by utilizing nuclear explosions. A large number of bombs of small energy yield must be stored on the vehicle, released at regular intervals, and exploded at an "appropriate" distance from the vehicle. The efficiency would be very low since most of the energy would be wasted because it would escape over a large, mostly ineffective area. The succession of millions of sharp individual impulses imparted to the vehicle could lead to structural damage. Consequently, a method must be devised, such as the use of powerful springs to smooth out (or damp) the impulses into a more-or-less continuous steady thrust. Finally, in order to experience appreciable thrust, the pusher plate must have a large area but unless the impulses from the exploding bombs are applied uniformly, the spacecraft will tend to tip over in one direction or the other.



Fusion Reactors

In addition to fission, there is another way in which nuclear energy can be released, fusion. Fusion (or combination) of the light nuclei is is distinct from fission (or splitting) of the heavy nuclei. Of the possible fusion reactions, four are of present interest; they are the only ones that may be utilized for the production of energy. These reactions shown in the illustration involve the nuclei of the two heavier isotopes of hydrogen; namely, deuterium (D^2), having a mass of 2 units and tritium (T^3), with a mass of 3 units, and of the lightest isotope of helium (He^3). The total energy of these fusion reactions is so high that, if the very small amount of deuterium present in one-gallon of ordinary water could be utilized completely, the energy released would be equivalent to that obtained by the combustion of over 300 gallons of kerosene.



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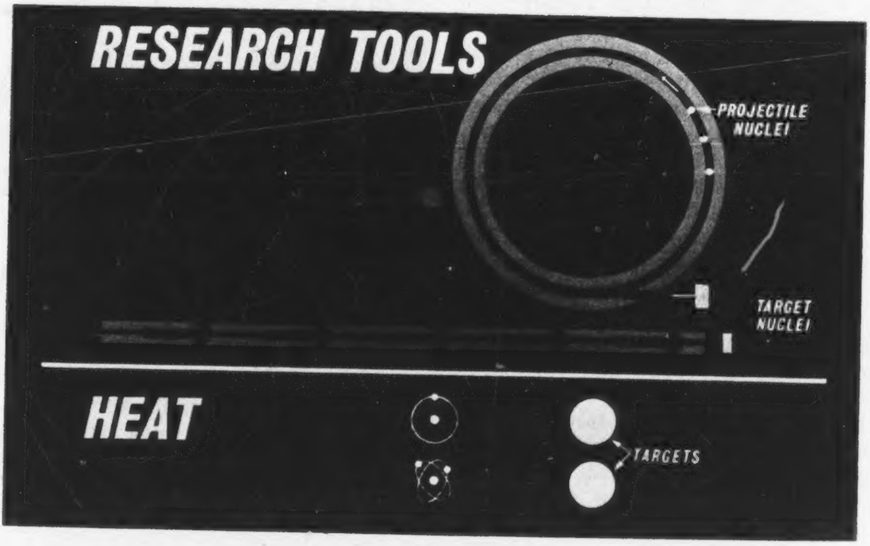
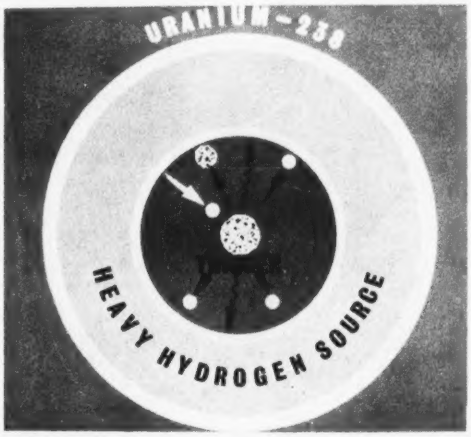
It is known that there are two general ways (or research tools) whereby nuclear fusion reactions can be brought about. The essential problem is to provide sufficient energy for one or both of the reacting nuclei to overcome the electrostatic repulsion of the positive charges they carry. When brought close together, there is a good propability that the nuclei will combine to bring about the appropriate fusion reaction. One method of supplying the necessary energy to the nuclei is to accelerate the reacting nuclei of one type to a high-velocity (and kinetic energy) in a charged-particle accelerator (for example, a cyclotron-like machine or similar device) and to cause them to impinge on a target consisting of the other reactant. But this procedure, although of great experimental importance has no practical value because the energy expended in accelerating the nuclei is much greater than is released by the fusion reactions.





The other way in which nuclei could acquire a large amount of heat energy is to raise their temperature. For example, it is possible to use the extremely high temperatures (tens of millions of degrees) attained in a nuclear fission explosion. Only at these temperatures will many of the nuclei of hydrogen and helium isotopes have sufficient energy to permit them to fuse and release energy; this is the principle of the so-called hydrogen bomb. The reactions are now described as thermonuclear because the nuclei acquire a high energy by virtue of their temperature.

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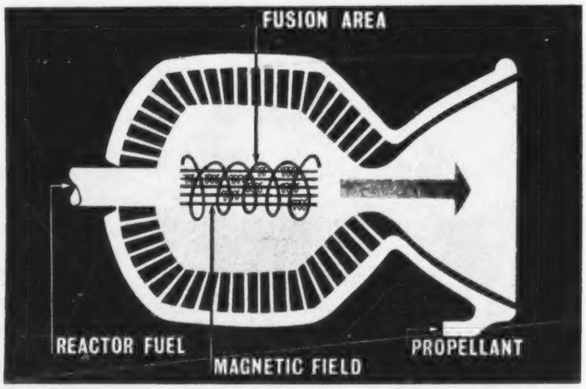
Of course, there is a remote possibility that thermonuclear (hydrogen) bombs could be employed for propulsion of a space vehicle by the procedure described in Project ORION for fission bombs. But it would be much more useful if thermonuclear reactions could be made to take place at controlled rate, rather than in the very rapid uncontrolled manner of an explosion. This matter has been the subject of much experimental study since 1951 as a means for producing nuclear energy for power purposes. If successful, a method could probably be developed for the utilization of fusion energy for rocket propulsion.

In order to establish a self-sustaining thermonuclear reaction, it would be necessary first to heat the gas (deuterium alone, or a mixture with tritium or helium-3) to a very high temperature, in the vicinity of 100 million degrees Centigrade or more. The fusion reactions could then take place fast enough to provide somewhat more energy than is required to heat incoming fuel gas to the appropriate reaction temperature and to allow for inevitable losses.



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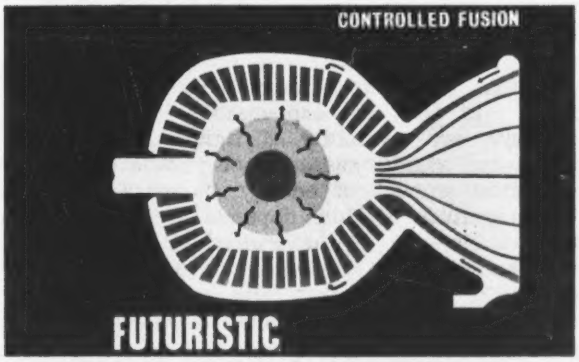
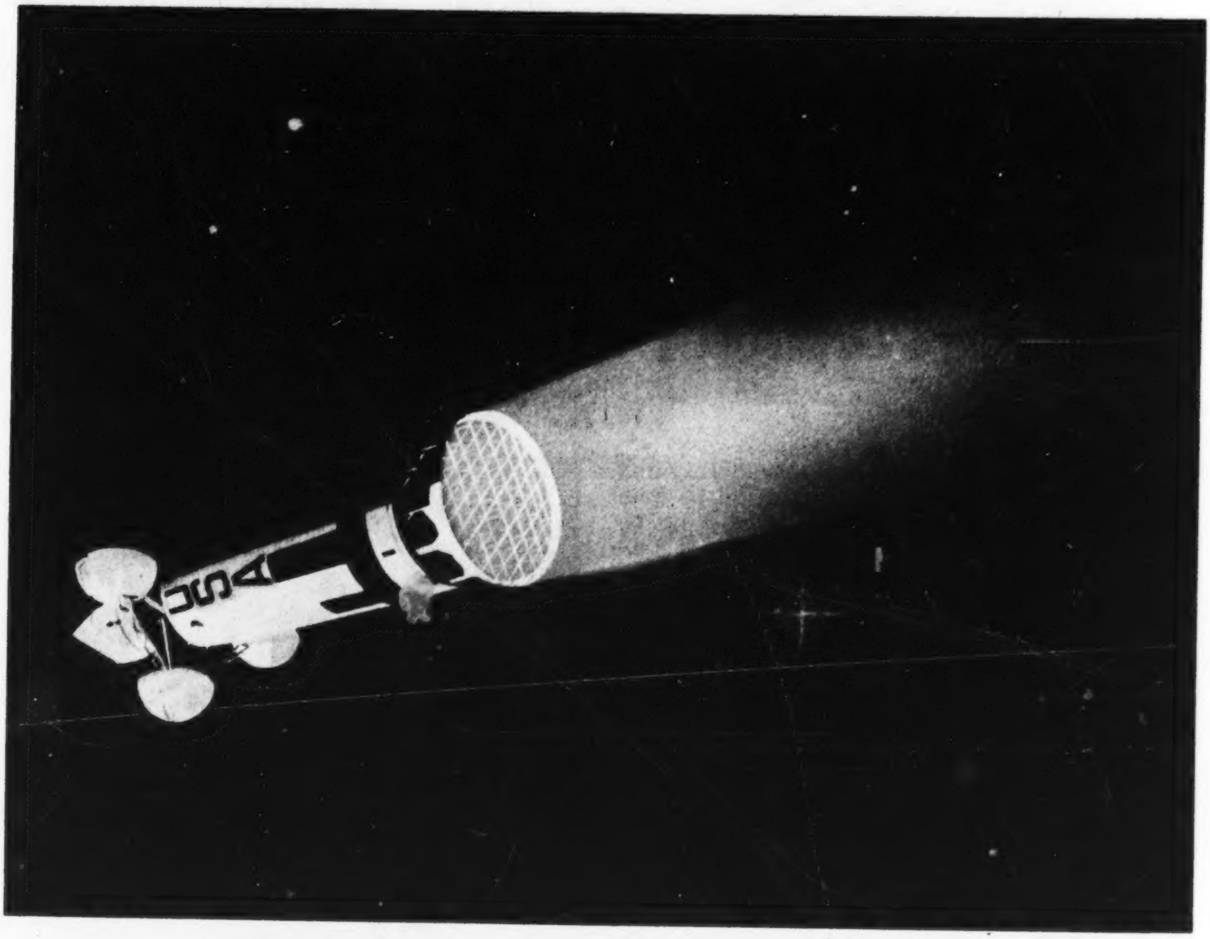


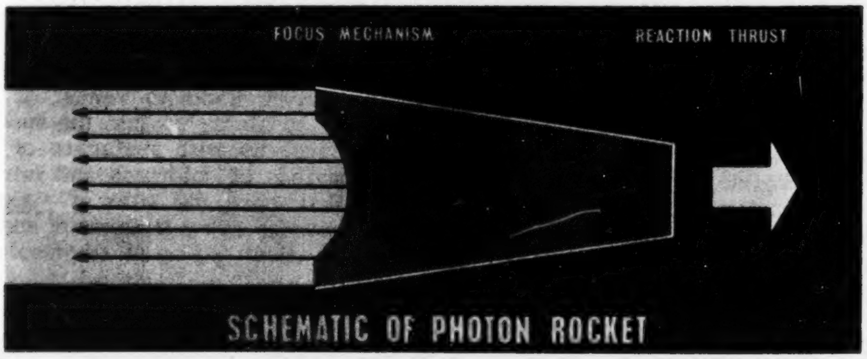
Since the initiation and maintenance of a fusion reaction requires the production of extremely high-temperatures, much hotter than the interior of the Sun, there is the difficulty of containing the reacting gases at such temperatures. The problem is not so much the heating of the vessel, but the loss of energy and rapid cooling of the gas particles when they strike the walls. A possible solution arises from the fact that, at high-temperatures, the fuel atoms are completely ionized to a plasma of electrically charged particles. In this event, theory indicates that the plasma might be confined away from the walls of the containing vessel by means of a magnetic field.



Photon Rockets

This fourth mode of rocket propulsion is different from any of those already considered, and possibly even more in the realm of speculation. The photon rocket is of unusual interest because it offers the prospect of space travel at a speed approaching that of light. If man is ever to leave the solar system and explore the stars beyond, such speeds will be required. The nearest star group to Earth; namely, Alpha and Proxima Centuri, is 4.3 light-years distant, that is to say, even traveling with the velocity of light the one-way journey would take 4.3 years. No other means of propulsion could provide velocities approaching that of light. Any lesser speed propulsion system would require more than a normal lifetime to complete the journey. It is for this reason, that the somewhat speculative concept of the photon rocket is being given serious consideration.

According to modern theory, all electromagnetic radiations are emitted, and travel from one place to another, as particles known as photons. All photons move with the velocity of light. In fact, the expressions "velocity of a photon" and "velocity of light" have exactly the same significance. Each photon carries a specified amount of energy, called a quantum, the magnitude of which depends on the frequency (or wavelength) of the radiation. It has been long known, even before the development of the theory of photons, that light rays and electromagnetic radiations, in general, can produce a pressure when they impinge on a surface. This radiation is ascribed to the impact of the photons.



A purely idealized design for a photon rocket is shown nearby. The engine consists essentially of a strong source of photons, for example, a solid body at high temperature, with a means of focusing the photons into a roughly parallel beam. Emission of the photons in the direction indicated would produce a reaction in the opposite direction, in the usual manner. The system would be equivalent to a rocket with an exhaust gas velocity equal to the velocity of light. The ideal specific impulse is equal to the exhaust velocity divided by the acceleration due to gravity at Earth's surface, that is, 32.2 feet per second per second. Since the velocity of light is 9.82 x 10^8 feet, it is seen that the theoretical value for the specific impulse of a photon rocket is more than 30 million seconds. However, the highly attractive prospect of such an exceptionally large specific impulse is offset by the enormous amount of power required to operate the photon rocket. For example, a contemporary photon conversion rocket that might develop a thrust of one pound would require 100 million times the heat energy of a chemical rocket, developing the same thrust. This great difference is due to present inefficiencies in converting fuel materials to light (photons). Because a photon rocket would have to operate for long flight periods, the mass of fuel would reach overwhelming proportions.

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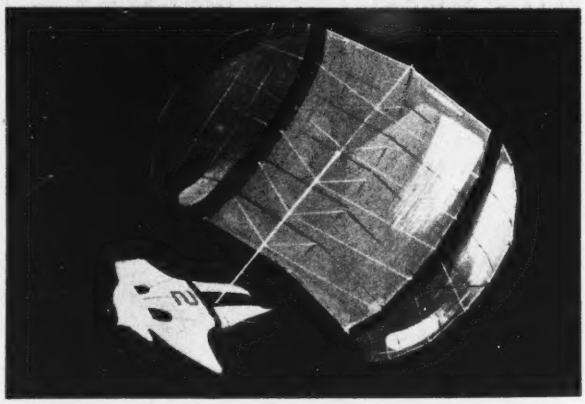
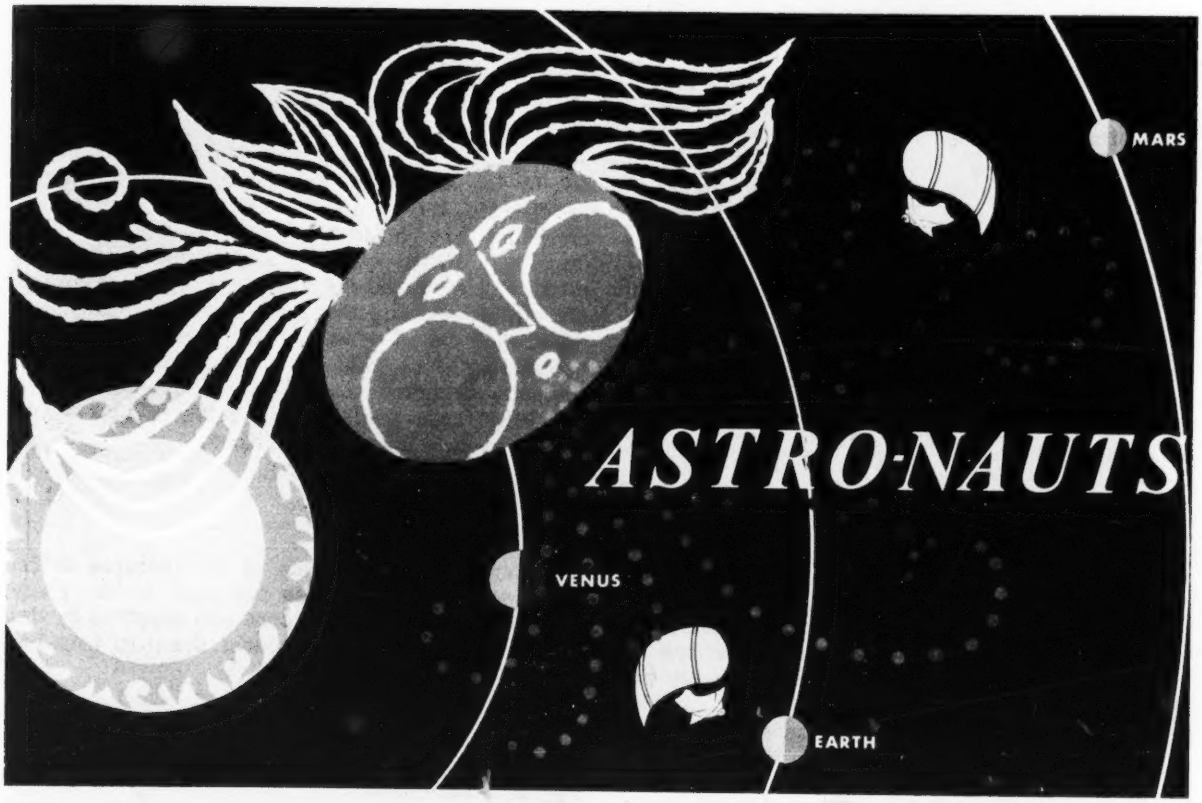
Solar Sailing

Finally, let us look at an entirely different form of photon propulsion that can perhaps be used within the solar system, but probably not beyond. This is the concept called solar sailing, which would utilize the pressure exerted on a surface by photons from the Sun. That the Sun's radiation does produce an appreciable thrust in the vicinity of Earth is known, for example, from the observed pertubations of the orbit of the ECHO I and ECHO 2 ballon satellites.

Solar sailing would be achieved by attaching to a vehicle a "sail" consisting of a large area of a strong, lightweight material. This might be plastic film, coated on one side with a thin layer of reflective aluminum. A solar sail with a reasonable area of 1000 square feet would develop a thrust of 2 x 10^{-4} pound. Although this is small, it would be produced continuously in space where gravitational forces are small, so that considerable velocities could be built up in the course of time. One of the features of the solar sail is that it does not have to carry any propellant, since the photons are supplied by the Sun. Consequently, the ideal specific impulse is effectively infinite.

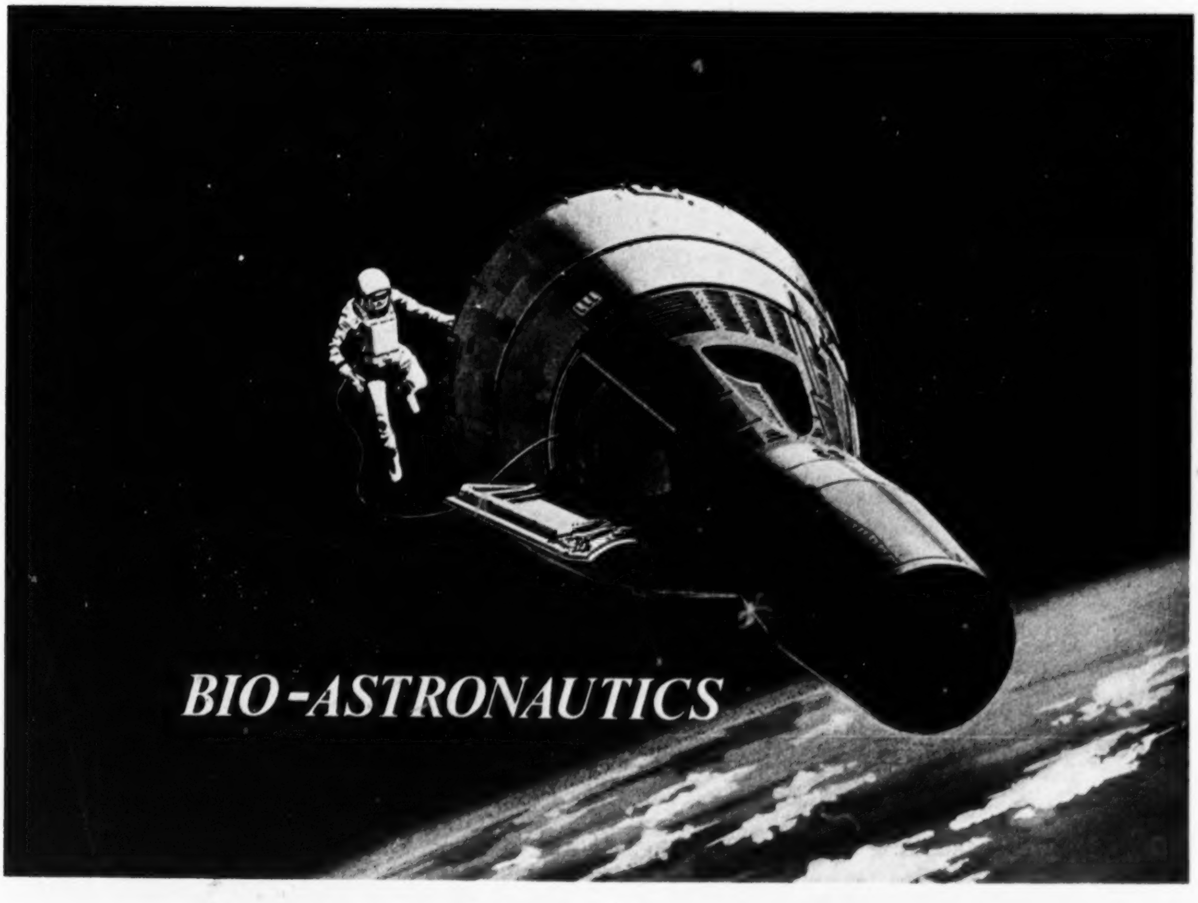


The solar sail vehicle could be guided to some extent by changing the direction of the sail with reference to the Sun; this would, of course, require the expenditure of some energy. Because of the large area of the solar sail, this technique could be employed only where aerodynamic drag is negligible, in the regions between the planets. Thus, solar sailing may be of interest for the propulsion of instrumented, unmanned interplanetary probes. It should be noted that the thrust per unit area due to solar radiation pressure varies inversely as the square of the distance from the Sun. Consequently, the thrust will increase steadily in a journey from Earth to Venus but will decrease in going to Mars, so that the space voyagers of the future, as with seafarers of the past, will face periods of doldrums and fair winds. They will truly earn the title of "Astro-nauts" as they face the many hazards of sustaining human life as they propel themselves about in space.



CHAPTER 7

BIOASTRONAUTICS



GENERAL

Bioastronautics, like the other space-oriented sciences, has come into its own on the rapidly rising tide of technological advancements which has characterized the 1960's. Man's age-old dream of travel to the stars is an extension of his indescribable urge to conquer the unknown. Now nearly within his reach lie the vast regions of space. Yet, eagerly poised on the edge of this void, he faces an environment which has no equal on Earth—an environment which will tax his body to the maximum.

UNITED STATES

MERCURY SERIES	DATE	ASTRONAUT	ORBITS	TIME
MR-3	5 MAY 61	A. SHEPARD	SUB ORB	15 MIN.
MR-4	21 JULY 61	V. GRISSOM	SUB ORB	15 MIN.
MA-6	20 FEB 62	J. GLENN	3	4.9 HRS.
MA-7	24 MAY 62	S. CARPENTER	3	4.9 HRS.
MA-8	3 OCT 62	W. SCHIRRA	6	9.2 HRS.
MA-9	15 May 63	L. COOPER	22	34.3 HRS.
GEMINI SERIES				
G-3	23 MAR 65	V. GRISSOM J. YOUNG	3	4.9 HRS.
G-4	3 JUN 65	E. WHITE J. McDIVITT	66	97.9 HRS.
G-5	21 AUG 65	L. COOPER C. CONRAD	128	190.9 HRS.
G-7	4 DEC 65	F. BORMAN J. LOVELL	220	330.6 HRS.
G-6	15 DEC 65	W. SCHIRRA T. STAFFORD	17	25.9 HRS.
G-8	16 MAR 66	N. ARMSTRONG D. SCOTT	6.5	72.3 HRS.
G-9	3 JUN 66	T. STAFFORD E. CERNAN	47	72.3 HRS.
G-10	18 JULY 66	J. YOUNG M. COLLINS	46	70.8 HRS.
G-11	12 SEP 66	C. CONRAD R. GORDON	47	71.3 HRS.
G-12	11 NOV 66	J. LOVELL E. ALDRIN	63	94.6 HRS.

EVA TIME	ASTRONAUT	UMBILICAL	STAND UP
G-4	E. WHITE	23 MIN.	
G-9	E. CERNAN	2 HRS. 8 MIN.	
G-10	M. COLLINS	38 MIN.	53 MIN.
G-11	R. GORDON	36 MIN.	2 HRS. 15 MIN.
G-12	E. ALDRIN	2 HRS. 9 MIN.	3 HRS. 28 MIN.

TOTALS

MEN	ORBITS	FLIGHTS	MAN HOURS	EVA TIME
19	677	24	1992.9	12 HRS. 29 MIN.

RUSSIAN

VOSTOK SERIES	DATE	COSMONAUT	ORBITS	TIME
VOSTOK I	12 APR 61	Y. GREGARIN	1	1.8 HRS.
VOSTOK II	6 AUG 61	G. TITOV	17	25.3 HRS.
VOSTOK III	11 AUG 62	A. NIKOLAYEV	64	94.4 HRS.
VOSTOK IV	12 AUG 62	P. POPOVICH	48	119.1 HRS.
VOSTOK V	14 JUN 63	V. BYKOVSKY	81	70.8 HRS.
VOSTOK VI	16 JUN 63	V. TERESHKOVA	48	70.8 HRS.
VOSKHOD SERIES				
VOSKHOD I	12 OCT 64	V. KOMAROV K. FEOKISTOV B. YEGOROV	16	24.3 HRS.
VOSKHOD II	18 MAR 65	A. LEONOV P. BELYAYEV	17	26.0 HRS.

EVA TIME	COSMONAUT	UMBILICAL	STAND UP
VOSKHOD II	A. LEONOV	10 MIN.	

TOTALS

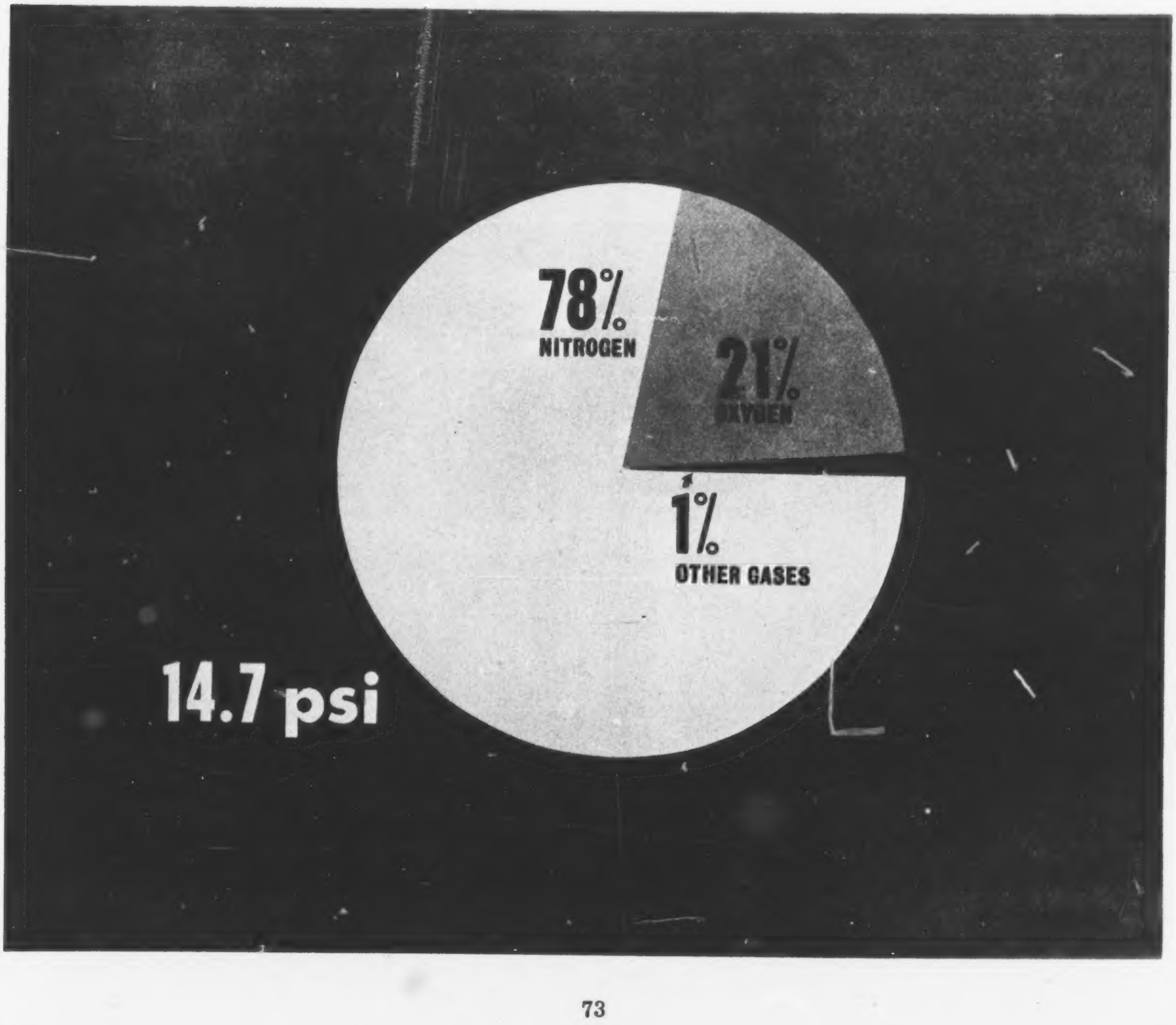
MEN	ORBITS	FLIGHTS	MAN HOURS	EVA TIME
10 + 1 WOMAN	293	11	507.3	10 MIN.

Between 1961 and the tragic flight of Cosmonaut Komarov in 1967, a total of 29 men and one woman spent over 2500 hours orbiting the Earth.

These figures, though impressive, represent a relative lack of experience when one considers the hostile conditions man faces in space. Hazards of radiation, intense heat and bitter cold, the disconcerting effects of long duration, weightlessness, cramped living conditions, altered eating and sleeping habits, all of these pose formidable problems to a space traveler. A tremendous amount of money and effort has been spent in an attempt to simulate the environment of space, but nowhere on Earth can one experience these rigors in a spacelike combination. Thus every manned mission has proven vital to subsequent flights because each developed man's ability to cope with the hazards of space. Let us now consider these hazards to manned spaceflight in more detail.

RESPIRATION

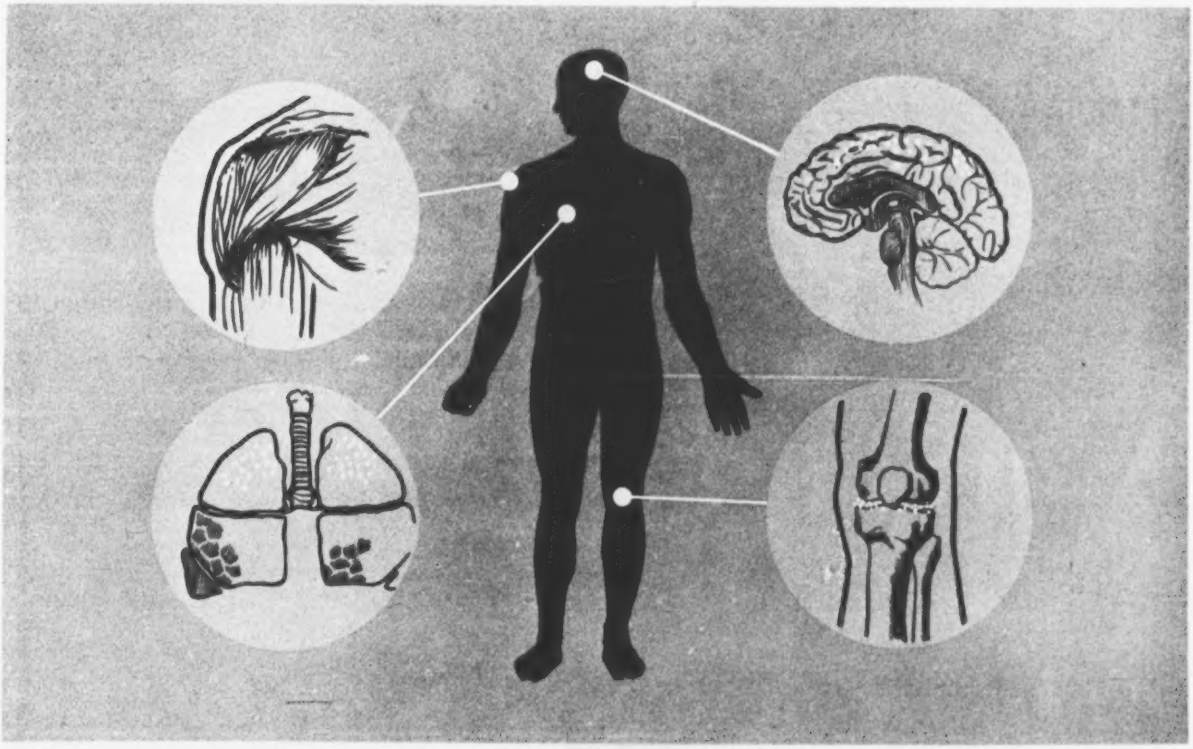
After the fiery tragedy in late January, 1967, (claiming the lives of Astronauts White, Grissom, and Chaffee) the selection of gases for human respiration while in orbit has come under close investigation. The original decision to use pure oxygen was reviewed extensively as committees and study groups reconsidered the pros and cons of single or a two-gas system. Obviously, the most important atmospheric gas for man's respiration is oxygen. In fact, if the brain cells are deprived of an adequate supply of oxygen for more than 4 minutes, irreversible brain damage occurs. But the body's need for atmospheric nitrogen is not so well understood. It was thought that nitrogen was simply an inert gas—not utilized by human tissue. Now there is reason to believe that nitrogen may play a vital part in respiration and lung mechanics and may possibly be a subtle component of man's physiological system. Thus for a simple status quo, one would be inclined to supply space travelers with a two-gas system (nitrogen/oxygen). This approach has been taken by the Russians for all but one of their manned flights. However, engineering problems do exist. The use of a two-gas atmosphere requires extra tubing, valves, and sensing devices to regulate the gas ratios. Furthermore, additional gases must be stored aboard and the spacecraft shell must be strengthened to withstand the higher pressures necessary for a two-gas system. These extras lead to a major increase in weight for the two-gas system.



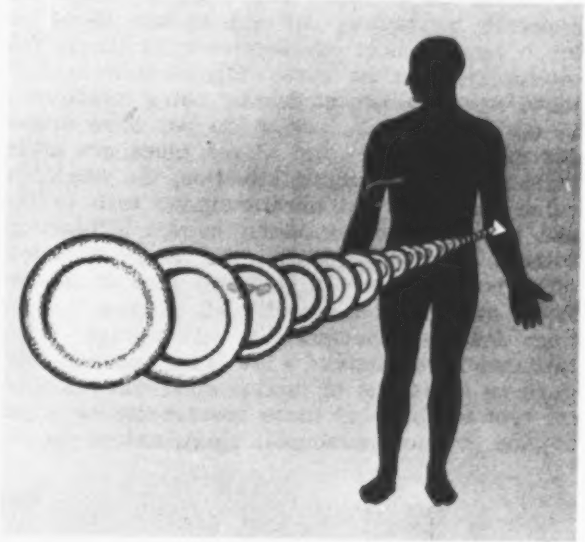
In addition, the use of a nitrogen/oxygen atmosphere has one serious drawback - danger from the bends! Just as deep sea divers may develop the bends when coming up from ocean depths, so astronauts can produce nitrogen bubbles when ascending from sea level to the zero pressure of space. In fact, anytime man is exposed to atmospheric pressures equivalent to 18,000 feet and upwards, he may suffer from nitrogen bubbling out of his blood and tissues into his joints, skin, lungs, and brain. Thus in Russian capsules, where oxygen/nitrogen atmosspheres are used at near sea level pressure, a sudden decompression would almost assuredly result in a case of the bends. The Russians, realizing this, had an elaborate system for respiration aboard the Voskhod II spacecraft when Leonov performed his 10-minute space walk. From liftoff to orbit Leonov was breathing 100% oxygen while his partner was inhaling the standard oxygen/nitrogen mixture. Thus, when it came time for Leonov to decompress and egress, he had purged most of the nitrogen out of his system and the bends posed no problem.

Historically, when drawing up plans for the Mercury Capsule, NASA was looking for a lightweight respiratory system easily tolerated by man. At that time many ground experiments had shown that a single gas system using 100% oxygen at reduced pressures could be employed for two to three weeks without apparent harm. Usable oxygen pressures lay between 2.5 psi and 7 psi. Breathing at oxygen pressures below 2.5 psi, one suffers from hypoxia (insufficient oxygen) and above 7 psi one develops symptoms of dizziness, coughing, numbness and the tingling associated with oxygen toxicity. Thus an atmosphere of pure oxygen at 5 psi seemed the least of all evils (avoiding heavy payloads, complicated two-gas systems, the bends, and so forth). Our Mercury astronauts successfully circled the globe 34 times breathing this unnatural atmosphere of pure oxygen.

In planning the Gemini flights the basic design change was to enlarge the Mercury Capsule to accommodate two persons. All systems that had been reliable were utilized. Since only short 14-day flights were planned for Gemini, and since space walks were important phases of the missions, Gemini also used pure oxygen.



However, the Apollo Program developed differently. In 1962 contracts were let for a two-gas atmosphere, 50% oxygen and 50% nitrogen at 7 psi. But when pressed for time, money, and weight, NASA planners decided to stay with the successful Mercury/Gemini oxygen atmosphere for Apollo. By the end of the Gemini series only one drawback to the pure oxygen system could be found. Blood isotope studies on Gemini flights 4, 5, and 7 revealed the astronauts were losing red blood cells. These are the vital cells which transport oxygen to the tissues. Something was destroying them. Frank Borman, on the 14-day Gemini 7 flight, lost an estimated 20% of his red blood cells. Presently, it is thought that the 100% oxygen atmosphere renders the red cells more susceptible to destruction. Although the medical experts are somewhat concerned about potential blood damage, they believe man can function effectively on a short mission breathing pure oxygen.



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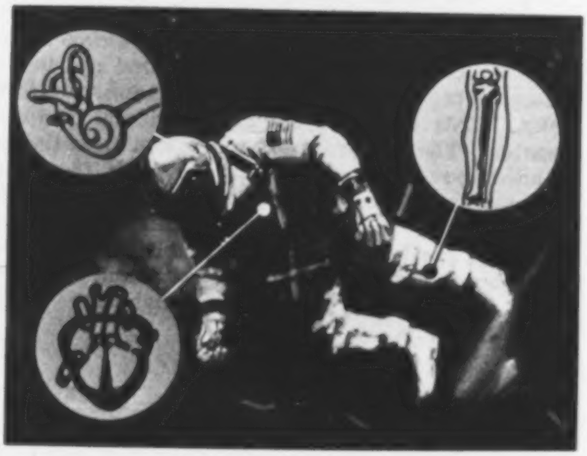
Thus, NASA is presently using a single gas system which is considered adequate for periods of 30 days or less (time enough to reach the Moon and return). But when speaking of manned interplanetary travel such as an 8-month trip to Mars, the present state-of-the-art for astronaut respiration is inadequate.

A two-gas atmosphere is being developed for the Apollo Applications Program, utilizing oxygen and nitrogen. In this program three men will circle the Earth at an altitude of 260 miles while conducting experiments for 30 to 60 days. This is well outside the safety zone for a pure oxygen system. It is obvious that further studies and experimentation including manned spaceflights are necessary to solve this vital respiration problem on such flights.

Before we conclude this topic, some note should be made of experimentation with oxygen diluted with gases other than nitrogen. Argon, neon, and krypton have been tested with oxygen for human-compatibility, but the expense of manufacture and necessary purification has generally prohibited their use. Extensive tests using helium have been conducted in the United States and Russia. These tests showed that man can function quite well in oxygen/helium atmospheres. Although it does not appear that helium protects one from the bends, it has been demonstrated that man can tolerate higher cabin temperatures due to helium's heat dissipating characteristics. Our Air Force has pioneered some of this work and has tentatively chosen oxygen/helium for the Manned Orbiting Laboratory. NASA, however, favors using nitrogen for its long term missions requiring a two-gas mixture.

WEIGHTLESSNESS

Weightlessness affects three of the body's systems directly: (1) man's organs of orientation, (2) the cardiovascular system, and (3) the musculo-skeletal system. In the Mercury series of manned flights the area of prime concern to NASA's doctors was the effect of weightlessness on man's balance and orientation. Normally



84

on Earth we maintain our balance using four separate indicators: our vision, our sense of touch and position, our semicircular canals and otolith organ in the ears. Signals from each of these systems are constantly being monitored. In space, however, cabins do not have wrap-around windshields and visual clues are often lacking. In a tumbling situation, the semicircular canals can give erratic signals to the brain, and the otolith organ nearly ceases to function without gravity. Finally, the sense of touch throughout the body is certainly altered as one floats away from the seat. All of these conditions lead to disorientation and vertigo. The Russians have admitted a few of their cosmonauts were on the verge of motion sickness. It is of interest to note that these cosmonauts were not trained aviation personnel. No American astronauts have experienced disorientation. In fact, cosmonauts and our astronauts with many hours of flight experience have denied any periods of disorientation. Thus, it appears that flight training or simulation training may be the answer to the problem.

Further studies with the effects of weightlessness on the vestibular or orientation system will be included in the Apollo Applications Program. A time and motion study utilizing movies of the astronauts while they perform daily tasks may reveal, among other things, their ability to become accustomed to the zero g of their new home. Also, an apparatus which measures occulogyral counter rolling (a phenomenon of otolithic action on the iris of the eye during pendular movements of the body) will be included in this orbiting laboratory.

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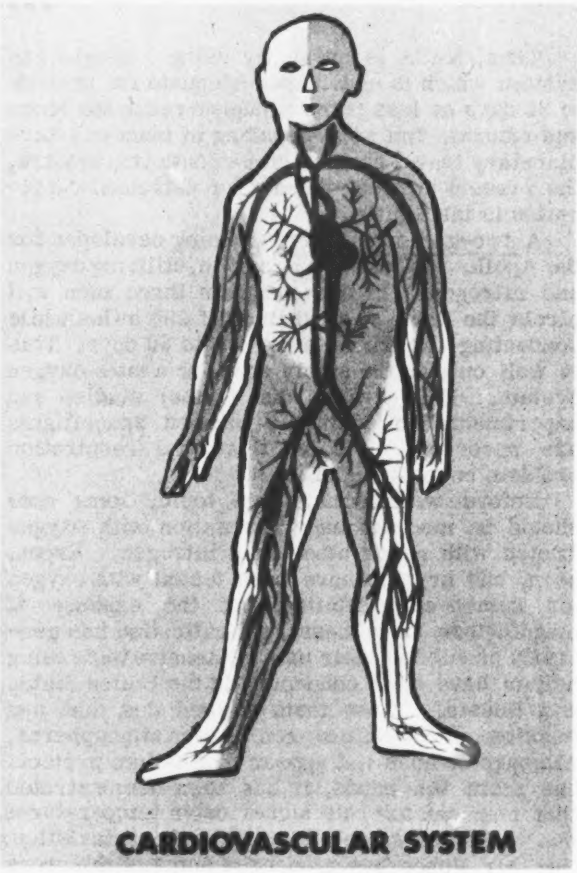
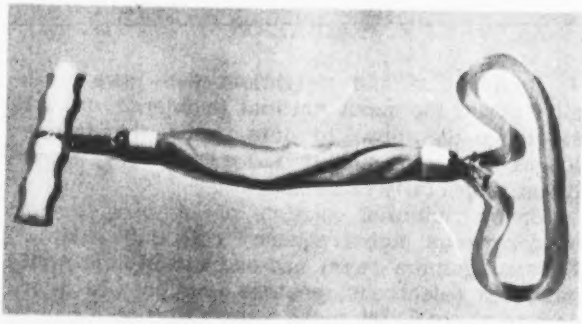
Weightlessness affects the cardiovascular system more directly. Man's heart and blood vessels are geared to a gravitational environment. The amount of blood within the vascular "tree", the volume and distribution of blood to the organs, and even the force of each heartbeat is influenced by gravity. In the weightless state blood tends to pool in portions of the body. Hormonal and neural regulatory mechanisms are triggered to compensate for this abnormal condition. Two Mercury astronauts and all of the Gemini astronauts have shown varying degrees of cardiovascular deconditioning after their flights. Their hearts and blood vessels adapted to the zero g of space and "relaxed" to a certain degree. After splashdown their blood systems were still relaxed so that when they stood up, their pulse increased, blood pressure fell, and some felt faint. This condition is called orthostatic hypotension. There was initial worry that these lightheaded periods might coincide with in-flight maneuvers or re-entry where excessive g's are encountered. Thus the astronaut could conceivably blackout during these critical periods. This has not happened and no detriment of function has been found on any of the flights.



CARDIOVASCULAR SYSTEM

NASA's doctors are attempting to remedy this cardiovascular deconditioning by various methods. In Gemini 7, James Lovell wore blood pressure cuffs on his upper thighs which inflated at various times and forced the heart to work harder in pumping blood to his legs. This did not fully alleviate the condition. Gemini astronauts also carried a bungee cord exerciser with them to help keep physically fit. In a future Apollo flight, an elastic garment will be donned from the waist down by the pilot prior to re-entry, utilizing the "G" suit principle to preclude orthostatic hypotension. And finally, in the Apollo Applications Program a large cannister with a waist diaphragm will be included. The astronaut will climb into the apparatus, seal himself from the waist down, and turn on the suction. A negative pressure will be applied to his lower body which will draw blood into his legs. It is hoped this may improve circulation and restore tone to the blood vessels and heart.



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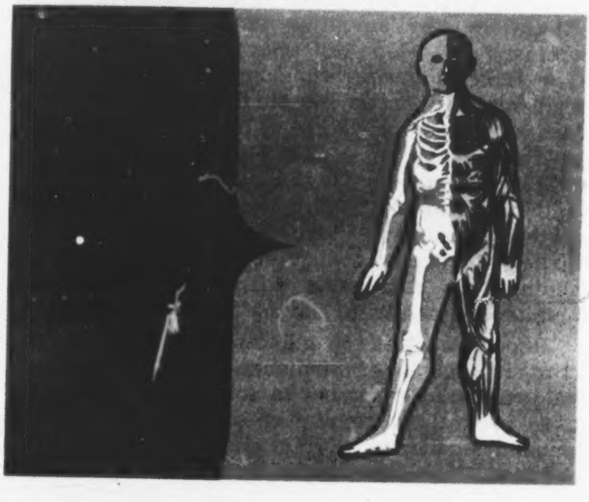
Finally, let's consider weightlessness and man's musculo-skeletal system. Past medical studies of paralytic patients had shown that long bed confinement or immobility led to atrophy or wasting of muscle and demineralization of bones. Apparently this is due to the fact that the stresses and strains placed upon muscles and bones during man's everyday flight to stand erect against gravity were no longer present. Thus the body felt no need to maintain muscular tone and retain minerals. Similar to bed confinement, weightlessness has the same effect on man. Although no muscular atrophy has been noted (primarily due to the short duration of the flights and the counter effect of the exercise regimen), a large calcium loss from various bones of astronauts has occurred. Through X-ray densitometry of hand and foot bones of Gemini 5 astronauts, a 13% to 15% calcium deficit was found in these areas after the near 8-day mission. This deficit leads to weaker bones, high levels of calcium in the blood, and a tremendous outpouring of calcium in the urine. A feared complication of this urinary excretion is the possibility of the formation of kidney stones - an intensely painful and incapacitating condition. Although extrapolation of the total body loss of calcium is not now possible due to apparent inequities of bone dissolution, this subject represents a significant area for future study. To remedy prospective losses, the astronauts now include one gram of calcium in their daily diets. This dietary supplement plus an exercise regimen significantly lowered the loss of calcium from the bones of astronauts on Gemini 10, 11, and 12 flights. However, calcium loss was not eradicated.

It is presently felt that the problems just discussed concerning the effects of weightlessness will be completely alleviated only by imposition of a pseudo-gravitational environment. This could be partially supplied by a spinning donut-shaped space station or an on-board centrifuge for the astronauts use.

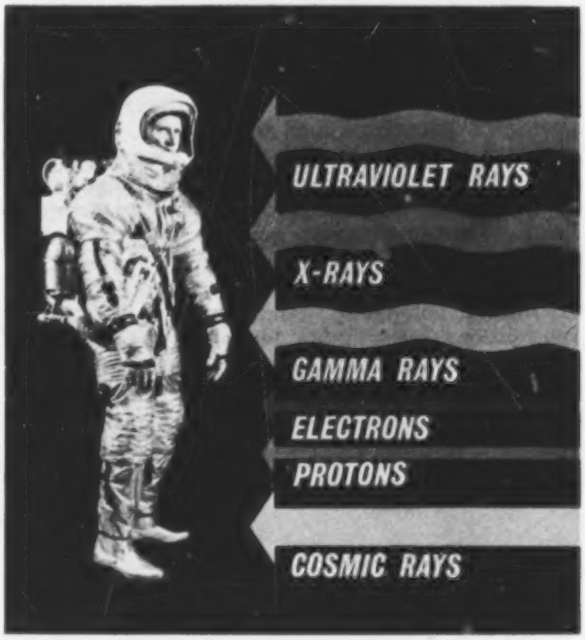


86

RADIATION

Respiration and weightlessness have probably posed the most critical problems to man's existence in space to date, yet with proposed longer missions, other hazards become significant, especially radiation.

Space radiation consists of an amalgamation of dangerous high frequency rays (ultra-violet, X-rays, gamma rays) and enormously energetic particles (electrons, protons, and cosmic rays). Any of these which make a direct hit on a human cell can cause damage. The greatest radiation hazards to man occur in two separate phenomena: Van Allen radiation and solar flare radiation. Peak intensities of radiation in the Van Allen Belt occur at an altitude of a few thousand miles above Earth. An unprotected man exposed in this area might receive a lethal radiation dose in a few hours. Because Mercury orbits were below the Van Allen Belts, radiation was not a hazard. Gemini orbits, however, were farther out and a few flights passed through the inner Van Allen Belt. Doses of radiation recorded by dosimeters carried on the astronaut's helmet, chest, and thigh ranged from 40 to 50 millirads on Gemini G-5 to 500-750 millirads on Gemini 10. Doses considered to be toxic to man range between 25 to 150 rads and upwards. Thus, the millirad exposure (1/1000 of a rad) seems slight indeed. However, there is concern for Apollo astronauts because they will penetrate the Van Allen Belt while on their journey to the Moon. Then, too, they will also be exposed to bursts of radiation caused by solar flare activity. Solar flares exhibit a cyclic pattern every 10 to 12 years. Solar flare intensities and occurrences are expected to be at a peak in the 1968 to 1971 period.



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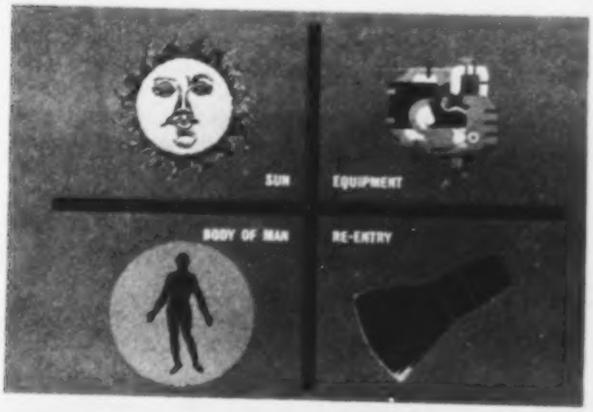
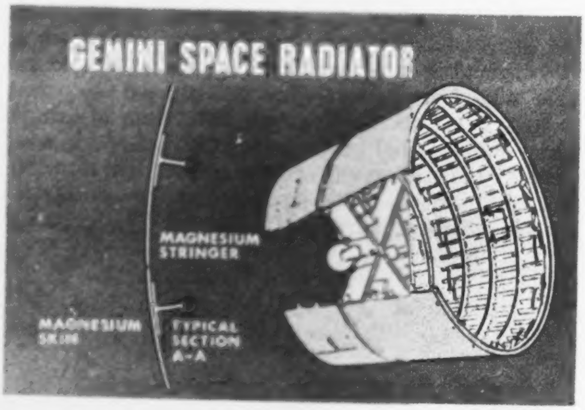
It has been calculated that astronauts will be protected from solar flare radiation while inflight by the shielding effect of the Apollo command module. But should they be exposed to a flare of moderate magnitude while in the lunar module, or on the surface during a space walk on the Moon, the radiation could cause gastrointestinal or hematologic damage. Presently, there are no provisions for total shielding of the astronauts as this would impose severe weight penalties. Therefore, should a solar flare of dangerous dosage occur during the lunar landing, the astronauts will simply abort the mission and return to Earth.

Recent studies of galactic radiation effects on man during long interplanetary missions reveal that continued exposure to low doses will result in an overall shortening of life span, and an increased incidence of malignancy or cancerous diseases. For example, it is estimated that for every 100 days of galactic radiation exposure, an astonaut's life would be shortened 20 days. This seems a calculated risk to chance for space exploration yet it is one of the many hazards confronting space travelers.

87





TEMPERATURE REGULATION

In space, disposal of heat poses a major design problem. Heat is added to the spacecraft by many means: The Sun, workings of internal equipment, re-entry maneuvers and even the body of man. The ingenious use of ablative materials to dissipate tremendous heat loads during re-entry is common. Changes in temperature due to exposure of the spacecraft to alternating periods of sunlight and total darkness puts quite a demand on the environmental temperature control systems. Mercury astronauts were cooled by the circulation of oxygen through their pressure suits. The excess heat was transferred to a stored water coolant and dumped overboard. The overall initial weight of stored water coolant that would have been required on Gemini and in the forthcoming Apollo missions was prohibitive. Hence a closed system to permit recirculation of water/glycol coolant through radiator panels in the spacecraft walls was employed. This method of regenerative cooling has proven quite satisfactory and temperatures of 70° to 75° were easily maintained for Gemini. It is hoped that during the Apollo missions the astronauts can shed their space suits and wear an inflight coverall garment whenever they are not in a powered phase of flight. Such natural physical comfort should lead to higher morale, enhanced performance, and better function of physiological systems.

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SPACECRAFT CONTAMINATION

With the lowered pressure inside the space cabin, and a relatively small closed living area, contamination of the cabin poses a serious environmental hazard. The astronauts' ability to overcome this respiratory hazard is hampered by a living space crammed with equipment. Insulation, paints, and plastics will "gas out" at reduced pressure yielding a variety of noxious gases. Effervescing organic materials yield benzene, formaldehyde, acetone, carbon monoxide, methane, and other toxicants. In fact, over 40 separate toxic organic gases were detected in a 32-hour simulated flight with the Mercury Capsule. Of course, this list doesn't include the multitude of contaminants which man himself produces. The short Mercury flights were unconcerned with this contamination hazard because the capsule leaked more oxygen by design than the astronaut breathed, hence there was a constant purging of contaminants. The Gemini capsule also leaked, and when one opened the hatch it was like a house-cleaning - all sorts of things floated away. Still only preliminary attention was paid to the materials used in construction of the Gemini interior. The Apollo module, similar to its two predecessors, will leak a 2-lb. per hour rate but two other safety factors will be included. Firstly, all materials used in construction of the spacecraft will be pre-tested in toxicology labs at reduced pressures. Secondly, a gas analyzer or chromatograph, which is able to detect and analyze 75 different gases, will be carried aboard the Apollo spacecraft. Cabin air will be periodically sampled for contamination, and if necessary, cabin purges will be made by venting to space.

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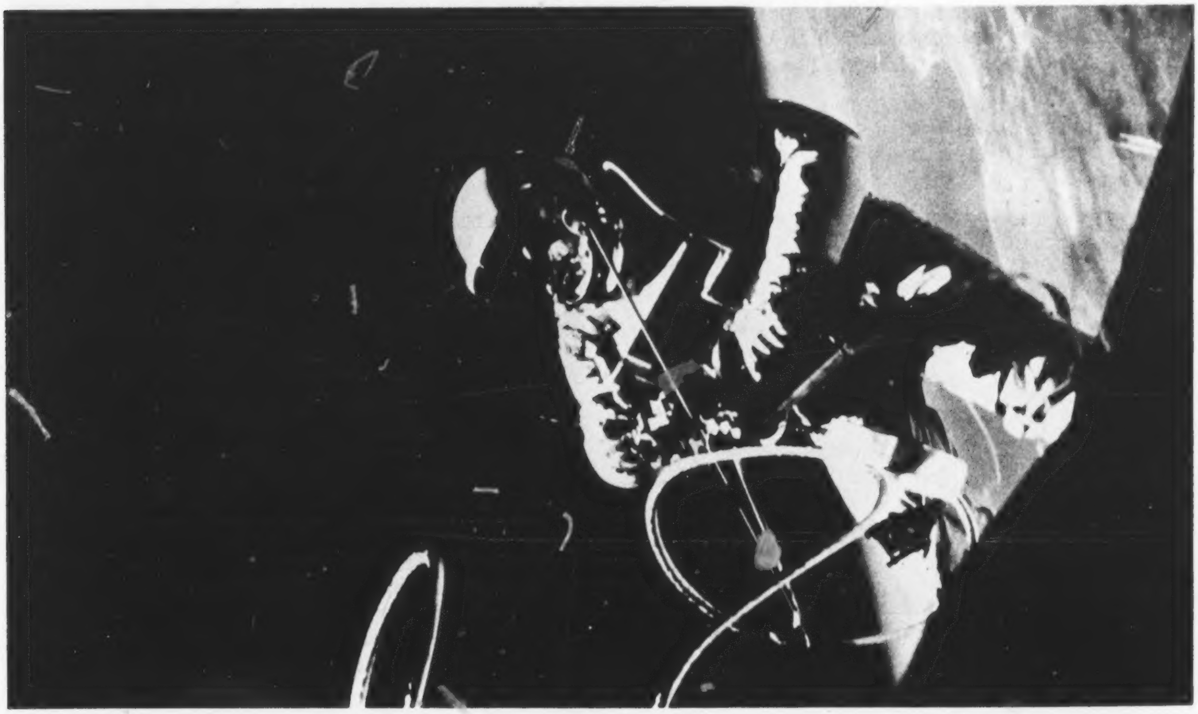
EXTRA VEHICULAR ACTIVITY (EVA)

One of the more important missions of the Gemini series was the assessment of man's ability to maneuver outside of his spacecraft during flight. Five Gemini astronauts spent a total of 12 1/2 hours standing up and "hanging" up in space. Ed White, our first astronaut to step off, spent 23-minutes "swimming" about the Gemini vehicle. Aside from testing feasibility of a hand-held maneuvering gun for moving from one point to another, his major purpose was to float about and evaluate his sensations. NASA used voice communications, an electrocardiogram, and respiratory rate measurements to assess the physiological and psychological impact on Astronaut White. Except for an elevated heart rate noted on egress and return to the capsule (probably due to work associated with camera mounting and closing the hatch), the walk was entirely successful. No physical degradation was noted.

However, during Astronaut Cernan's excursion in Gemini 9 on 3 June 1965, the first significant problem arose. During his EVA maneuvers the buildup of metabolic body heat exceeded the cooling capability of his suit and his mask fogged due to excess perspiration. His walk was ter-

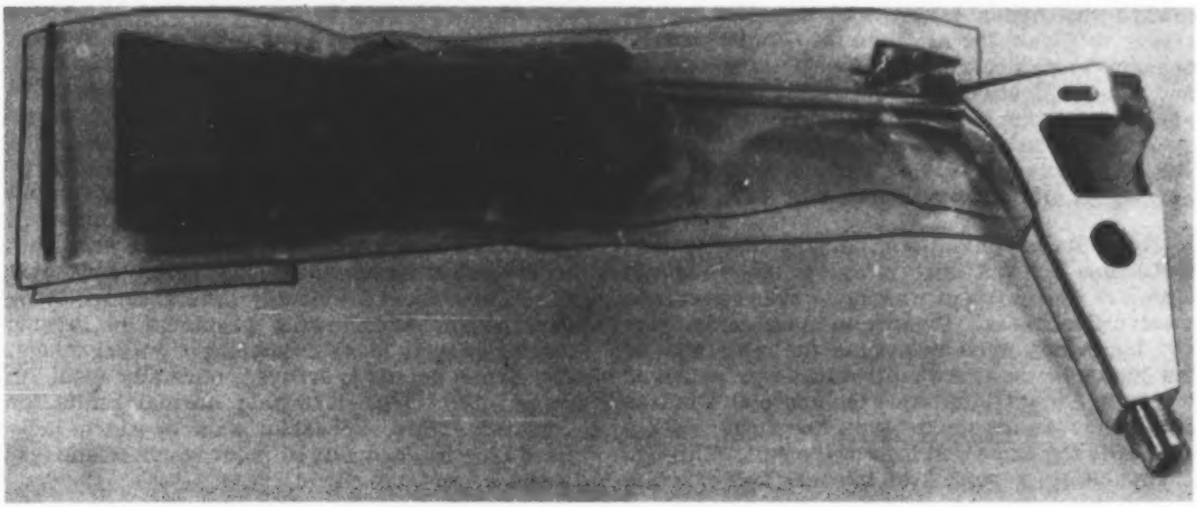


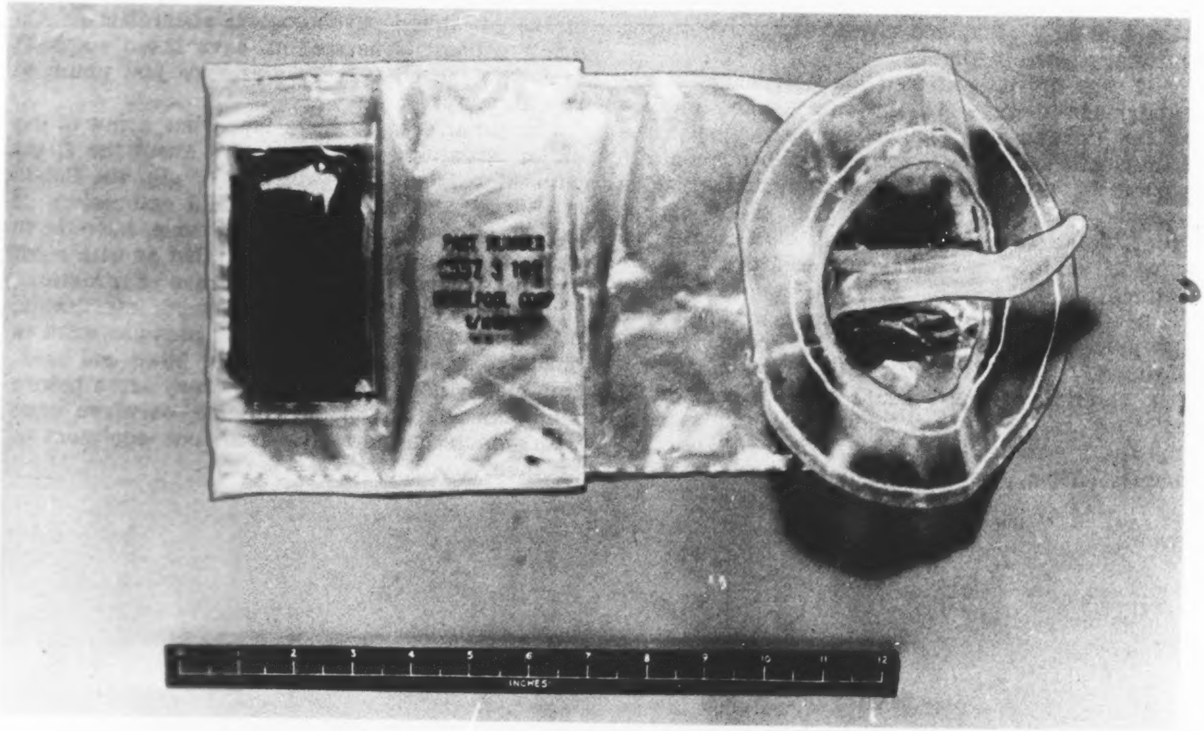
minated early. But probably the most disconcerting excursion was experienced by Astronaut Gordon on Gemini 11. His problems began even before egress when he became wedged in the spacecraft by his inflated suit. Then his gold-tinted helmet visor would not drop into place and he and Command Pilot Conrad worked for 30 minutes to free it. Finally, already tired, he made his way out into space and maneuvered toward the Agena target vehicle. The task of trying to tether the Agena to the Gemini capsule became monumental. His heart rate doubled and his respirations nearly tripled as he struggled to accomplish the maneuver which was expected to be simple. His vision became blurred by perspiration and he was called back to the spacecraft after only 36 minutes of EVA.

After these somewhat unnerving experiences, it became evident that space walks were not simple. The work of walking in space seems to involve two areas. Firstly, to move one's arms and legs, man must overcome the resistance of the joints in the space suit which is pressurized to about 3.5 psi. Inflating the space suit is like blowing up a surgeon's glove, the fingers stand out as do the arms and legs of the suit. Through manipulating a series of internal and external straps, the astronaut may be "drawn up" into a semi-sitting position with his arms partially flexed. To move the legs and arms further to accomplish tasks is all work. Secondly, man is a victim of Newton's "action-reaction" principle. Every movement of the arm or leg causes a small but significant opposite movement of the body in space. Hence, applying pressure and torque to objects is impossible unless one is well braced and coupled to them. Thus, NASA chose to postpone Gemini 12 for over a week to allow Astronaut Aldrin to practice various tasks in an underwater simulator. More hand and body holds were added to the spacecraft's outer skin so Astronaut Aldrin could brace himself while he worked. The extra briefing, training, and hardware changes paid off handsomely when Gemini 12 set a new EVA record (5 hours and 37 minutes). Two hours and 9 minutes of this time was spent in free-floating umbilical activities and most difficulties noted previously were absent. Astronaut Aldrin reported no problems in turning screws or tying knots, in pushing or pulling things. At no time did his heart rate, normally about 70; exceed 130 which is within normal limits for exercise. This successful walk by Aldrin indicates man can and will be able to work effectively in space.

FOOD

Food interests everyone including astronauts as mealtime is a welcome change from the rigors of spaceflight. The preparation of food for spaceflight is a complicated task. The daily metabolic and caloric requirements of man must be supplied, yet certain limitations on the types and forms of food must be observed. The meals should be of low fiber content (to minimize bulky waste) and they should be low flatus producing (to minimize intestinal gases). The food must not crumble or flake in the spacecraft, and liquids cannot be allowed to disperse under weightless conditions. Within these limitations the resulting food must be palatable, aesthetically acceptable, light, and easily stored. For the last Mercury and all of the Gemini flights bite-sized, rehydratable foods were available. In all, about 50 items were prepared, similar to those in the illustration. A water gun similar to the one illustrated was used to re-hydrate some foods. This gun also served as a source for drinking water. Since only cold water was available on Gemini flights, the dieticians had a difficult challenge to supply palatable meals. Between 2000 and 2500 calories (1 dietic calorie = 1000 small heat calories) per man per day were routinely supplied unless special metabolic studies including food utilization aspects were being conducted. Few problems were encountered with the food in general, and astronaut acceptance was good. Early Gemini flights scheduled four meals a day, but a schedule of three meals a day based on Cape Kennedy time has proven more acceptable. Apollo flights will have more diverse food items available. It is hoped that foods such as weiners, ham, and chicken loaf will be carried in the natural form. An important added feature in the Apollo module will be a recessed hot water spigot. Appropriate re-hydratable foods may then be reconstituted with water at 150°F, thus enhancing their taste appeal.





WASTE CONTROL

With the advent of longer space missions the control of human waste becomes increasingly important. Urine disposal has been easily accomplished by venting it overboard to free space where instant evaporation occurs. But the dumping of solid excreta into space has not been done and all solid waste has been carried back to Earth.

Astronauts for short Mercury flights were placed on a low residue diet 5 days prior to liftoff, thus avoiding need to consider waste management. Besides, the Mercury space suits were not designed to allow defecation. But the longer Gemini flights, by necessity, required changes. The suit was redesigned with a zipper which extended downward from the lower abdomen between the legs and up the back, thus providing access to the genital areas. A plastic bag, as depicted in the accompanying illustration, was carried by the astronauts. The opening of the bag was ringed by an adhesive surface which was applied around the anus to effect a seal. After defecation a disinfectant pill was added to the bag of waste which was stored aboard until recovery.

The Apollo module will have a small toilet chair arrangement. A semi-permeable double-walled bag (which will allow gas flow but not water or solids) will be placed on the seat ring. A series of gas jets in the ring will direct a flow of air down thru the bag, thus drawing solids toward the bottom. The solid wastes will be stored aboard and returned to Earth. Much of the urine and stool on future missions will be analyzed chemically for metabolic studies on food assimilation.

Projected plans for using human waste involve recovering potable water from the urine and stool. The remainder of the material could be detoxified and fortified with mineral supplements and used as fertilizer for ecological systems on interplanetary flights.

PSYCHOLOGICAL FACTORS

A review of the problems of manned space flight would be incomplete without mention of psychological considerations. Astronauts will be confined to a small living area, their tasks may become routine, and they will be exposed to fatigue, altered sleep patterns and confinement. Yet frequently they will be required to stay mentally alert and physically active during critical phases of flight.

It was initially feared the astronauts might experience feelings of isolation or separation such as the "break off" phenomenon experienced as a dissociation from Earth which has been reported by pilots flying at high altitudes. Men exposed to stringent tasks and under stress from isolation and fatigue might also experience a wide variety of visual and auditory hallucinations.

In the Mercury series ample contact with the astronaut was maintained by ground control stations. There was little time for monotony! The Gemini "twins" could talk to each other as well as to communicators on the ground, and their waking hours were filled with experiments. Thus, there has been no evidence of any of the predicted psychological aberrations. On a few occasions astronauts have taken amphetamine to increase their alertness just prior to re-entry.

In summary, we have noted but a few of the major stumbling blocks strewn about the flight path of man as he ventures to "slip the Bonds of Earth". With the successful completion of the Gemini flights many questions have been answered and problems solved, but as with most progress, new questions and areas of investigation are revealed. There is enough information presently available to say that man can exist in space long enough to get to the Moon and back. But many more subtle factors may arise before man can visit planets with the carefree ease with which he now flys from one continent to another.

CHAPTER 8

AUXILIARY SYSTEMS

POWER SUPPLIES

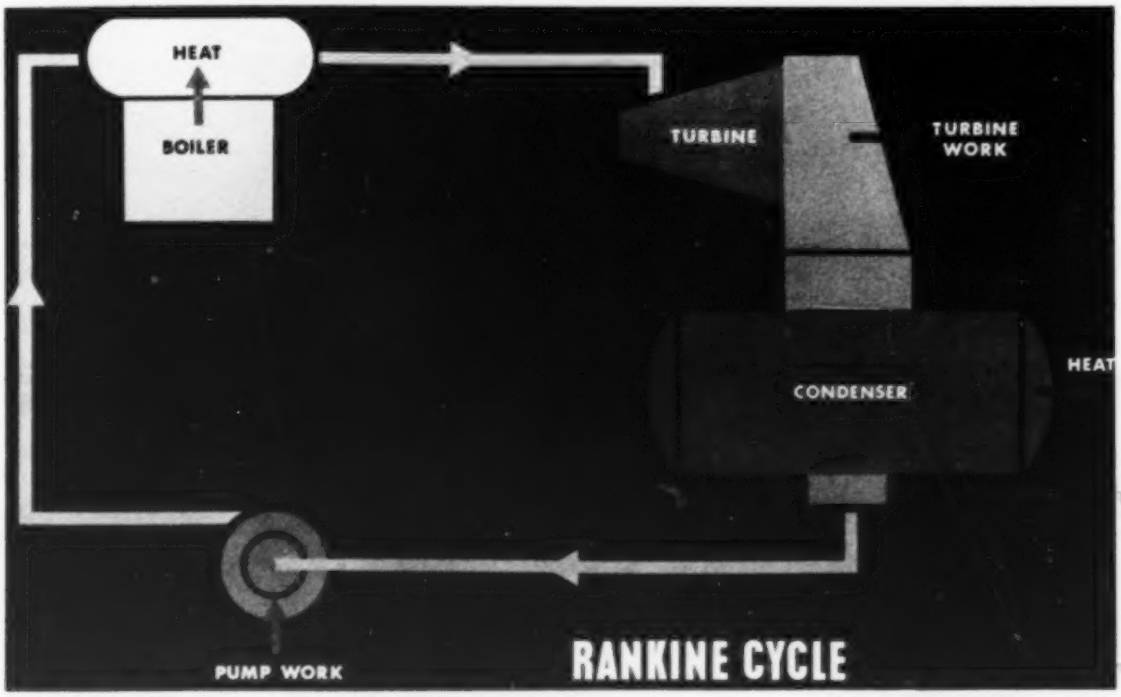
GENERAL

The most reliable source of auxiliary power to date on space vehicles has been the solar cell. Much work has been done in developing solar cell arrays, and many significant improvements have been made. However, the solar cell hasn't met the requirements for the large amounts of power necessary. It is for this reason that nuclear devices, heat storage devices, fuel cells, and chemical fuel engines are receiving more and more attention.

In this section we will discuss two primary categories: First, those systems which convert heat energy from some source into electrical power; and secondly, those systems which produce electrical power more directly.

CONVERSION TECHNIQUES

There are three principal methods of converting heat into electrical power under development at present. These are the turbogenerator (using a Rankine cycle or Brayton cycle), thermoelectric, and thermionic conversion.



Most readers are familiar with the Rankine cycle which is used to drive a turbogenerator. The Rankine cycle uses heat to boil a liquid, and the expanding vapor or steam drives a turbogenerator to produce the electrical power. The vapor is then condensed by cooling before being returned to the boiler. In space, the only method available for cooling is by discarding heat as radiation. The operating temperature of the working fluid must be high, since condensation by loss of heat through radiation becomes significant only at high temperatures.

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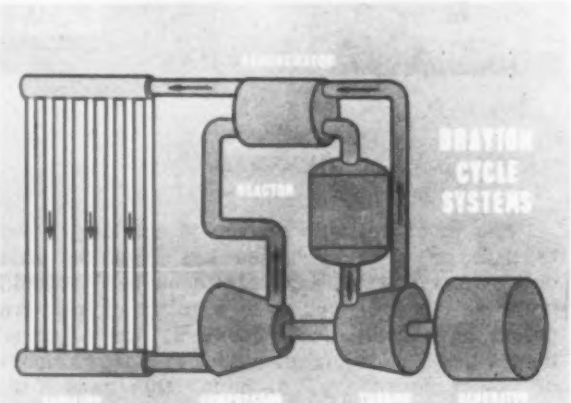
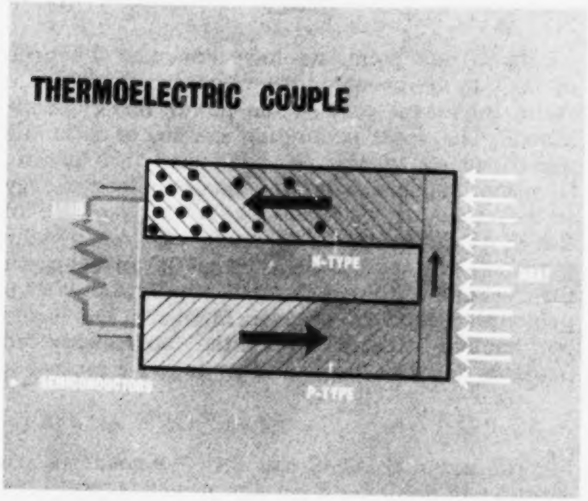
The other thermodynamic cycle considered for use with the turbogenerator is the Brayton cycle. Cold argon gas is compressed and then passes through a regenerator in which it is preheated by hot gas from the turbine exhaust. The gas is then heated to a maximum temperature in the reactor and is expanded through a turbogenerator. The gas passes through the regenerator where it gives up some of its heat to the gas leaving the compressor. Heat is also given up in the radiator before the cooled gas enters the compressor to pass through the cycle again.

For the same temperature limits the Brayton cycle is less efficient and requires a larger radiator than the Rankine cycle. Yet, the Brayton cycle is receiving increased attention today because it may alleviate the problems in the condenser, as well as corrosion and erosion present in the turbines that use the Rankine cycle.





Because a conventional turbogenerator involves moving parts, consideration is being given to other techniques for converting heat into electrical power which are mechanically more simple. One of these makes use of the principle of thermoelectric conversion. It is well-known that if one junction between two different metals is maintained at a higher temperature than another similar junction, an electromotive force is produced. Present day devices use semiconductors to produce this electromotive force because of the larger power attainable. This electromotive force can drive an electric current through a load connecting the hot and cold junctions. If we use our heat source to keep one junction at a high temperature, and a radiator to keep the other junction cold, a device is then available for generating electrical power without any moving components. A disadvantage of the thermoelectric system is its low efficiency for converting heat into electrical power.

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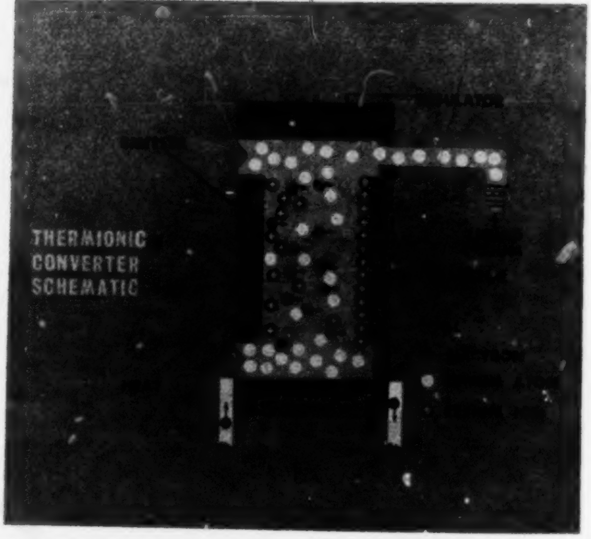
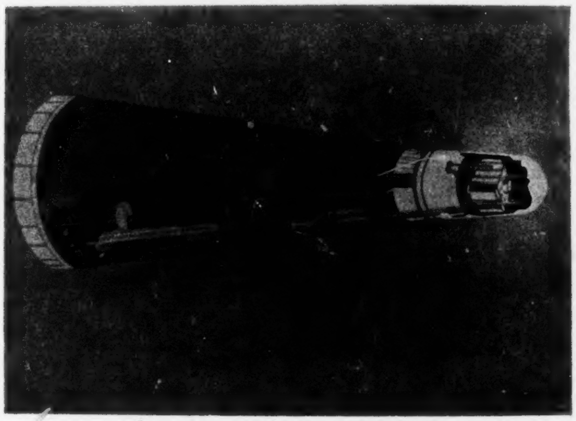
This direct generation of electrical power without a turbogenerator can also be achieved by thermionic conversion. Basically, the converter consists of two electrodes of different metals. One of these, preferably the one with the larger thermionic work function is maintained at a higher temperature than the other. Both electrodes tend to emit electrons, but the hotter one will do so more copiously. Since the electrons carry a negative charge, a positive charge will build up on the hotter electrode, referred to as the emitter. A negative charge will tend to form on the other electrode, called the collector. There will thus be a difference of potential between the two electrodes which can cause a current to flow. If heat is continuously supplied to the emitter and removed from the collector, there will be a steady flow of current. The result is somewhat analogous to that described for the thermoelectric converter.

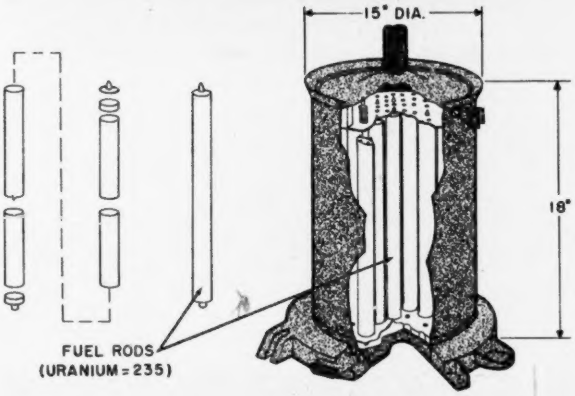
Thermionic energy conversion appears attractive for space power generation because it is a lightweight, efficient, high temperature device without moving parts.





SNAP

Up to this point, we have assumed a source of heat to be present, but obtaining that source is an important part of the power supply problems. The most promising method of obtaining significant quantities of heat, and thus power, in space, appears to be the use of nuclear energy in reactors or radioisotopes. The purpose of the SNAP Program is to study various nuclear systems of these kinds. SNAP is an acronym for Systems for Nuclear Auxiliary Power. SNAP projects identified by even numbers are based on nuclear fission while the odd numbered projects involve the use of radioactive isotopes.



The early SNAP-2 and SNAP-8 reactors are similar in design except for power output. The SNAP-2 was intended to produce 3 kilowatts of electrical power and the SNAP-8 roughly 35 kilowatts. In each case, the reactor core, which has a cylindrical form some 18 inches in length and 15 inches in diameter, is made up of a number of fuel rods consisting of uranium-235 mixed with zirconium hydride as a moderator to slow fission neutrons. The choice of zirconium hydride as moderator and of liquid sodium potassium as coolant for the reactor was determined largely by the need for compactness and the ability to function at high temperatures for extended periods.

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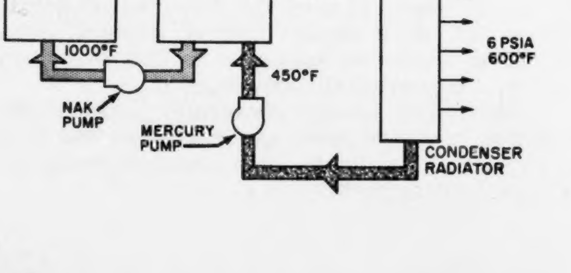
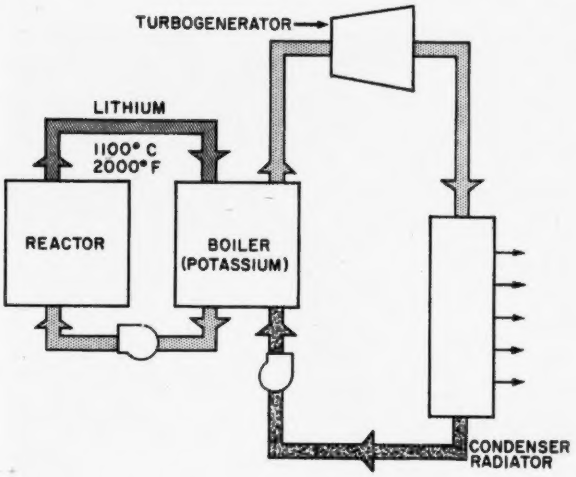
To convert the heat gained from the reactor core into electric power, the high temperature sodium-potassium coolant is passed through a boiler where it transfers heat to liquid mercury, the working fluid. The emerging coolant is circulated back to the reactor core. The mercury vapor drives a turbine connected to an electrical generator. In completing the Rankine cycle, the mercury vapor leaving the turbine is condensed to liquid before returning to the boiler.





SNAP-50 as initially conceived was to be an advanced reactor system, with a design power of 300 to 1000 kilowatts of electrical power. The coolant was to be an alkali metal, possibly lithium, and boiling potassium was to be the working fluid for the turbogenerator in this Rankine cycle. Both lithium and potassium are very corrosive at high temperatures. There are only a few metals like colombium, tantalium, and tungsten, or their alloys, which are able to contain lithium under these conditions. Since there has been essentially no prior experience in the use of lithium and boiling potassium under these conditions, much research and development are required before such a system as the SNAP-50 can become an operational system.

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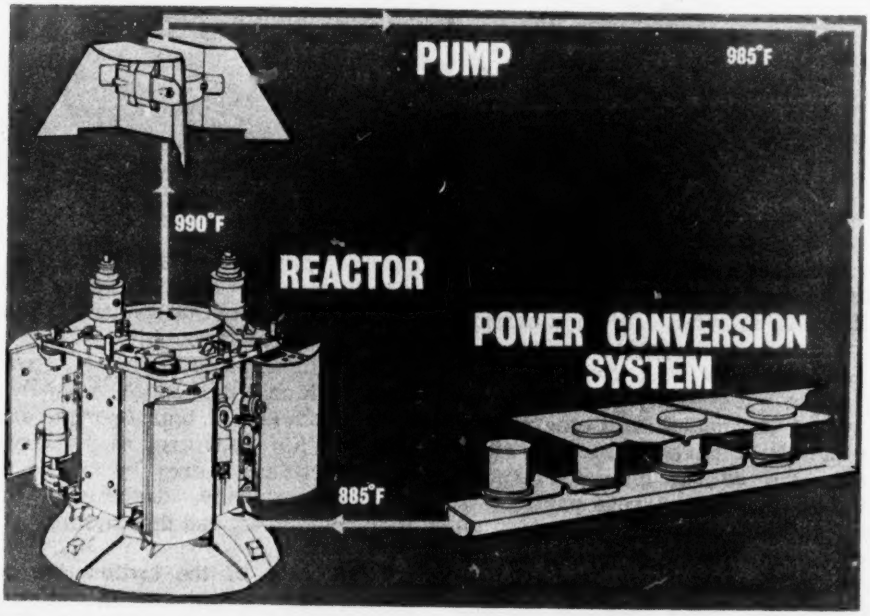
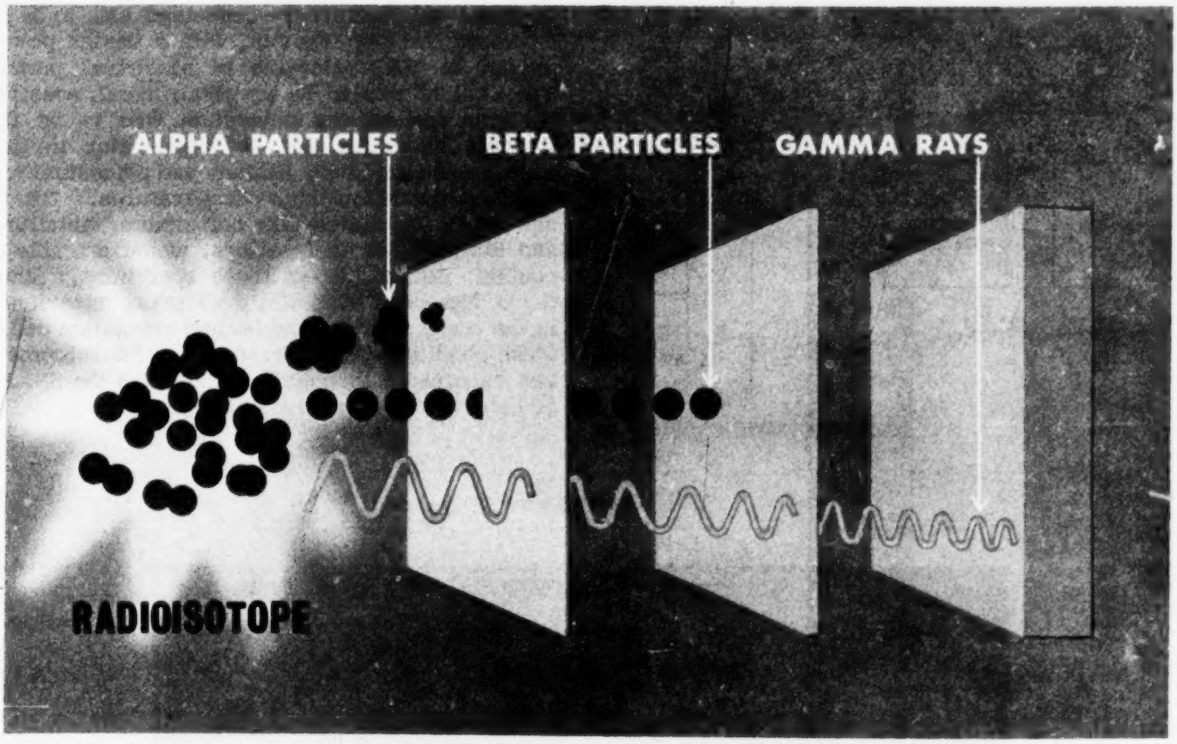


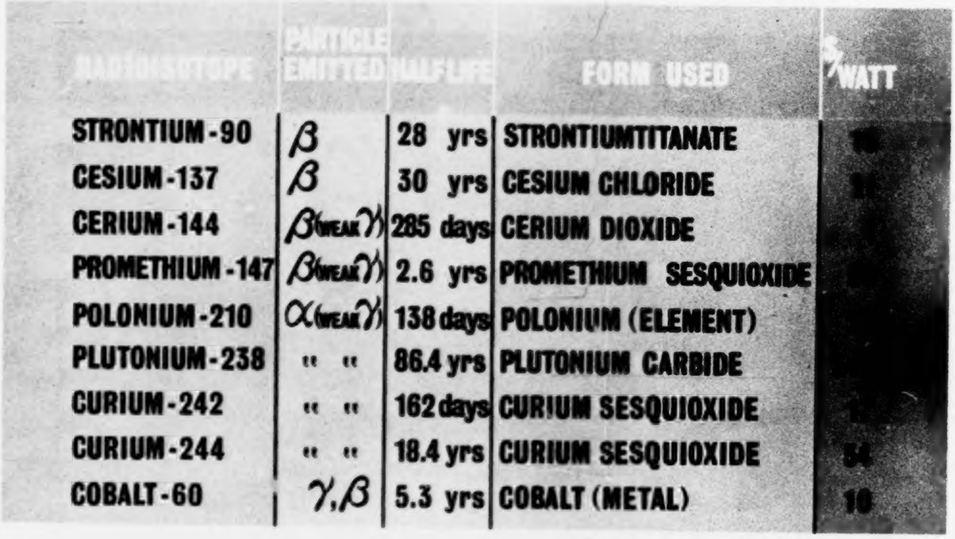
On April 3, 1965, SNAP-10A was placed in orbit to test the thermoelectric conversion concept utilizing fission heat. The general design of the core is similar to that of the other SNAP reactors. It used a sodium potassium liquid as the working fluid which was brought to a boil in the reactor. A number of thermoelectric elements, made from a germanium silicon alloy were connected in series and arranged in the form of an annular shroud. The junctions on the inner surface were heated by hot sodium potassium coming from the reactor, whereas, the junctions on the outer surface were cooled by radiating into space. The design power of the SNAP-10A was one-half of a kilowatt and it operated successfully for 43 days in orbit until a voltage regulator failure caused shutdown.



Let us now consider the odd numbered SNAP systems: those power supplies based on the phenomenon of radio-activity. Most elements can exist for a time in unstable, radioactive forms called radioisotopes. A characteristic manifestation of the instability or decay of radioisotopes is that the nuclei emit electrically charged alpha and beta particles. The alpha particle is the same as the charged nucleus of the normal helium atom, a beta particle is identical to a negatively charged electron. As a consequence of this particle emission, the original nucleus is converted into the nucleus of a different element. This daughter nucleus may be stable or it, in turn, may be radioactive, and undergo further radioactive decays. Many radioactive changes are accompanied by emission of gamma rays, which are electromagnetic radiations of very high energy. Like X-rays which they resemble, gamma rays can penetrate appreciable thicknesses of matter.

Alpha and beta particles are absorbed quite readily in solid material. When such absorption takes place, a considerable amount of the kinetic energy carried by the particles is converted into heat. The kinetic energy of the decay particles arises from the parent radioactive nucleus and is a form of nuclear energy resulting from conversion of mass to energy. Radioactive materials, which emit large numbers of alpha and beta particles of high energy, are a source of heat. This heat can, in principle, be changed into electrical energy by any of the conversion methods already described; turbogenerator, thermoelectric, and thermionic.

The rate of the radioactive decay process, or the rate of emission of radiations, is usually expressed in terms of the half-life of the individual radioisotopes. Half-life may be defined as the time required for the radioactivity of a given quantity of a particular radioisotope to decay to half of its original value. Each radioactive element has its own half-life that is independent of its physical state or the amount of material present. Half-lives of various radioisotopes range from a very small fraction of a second to many billions of years.



RADIOISOTOPE	PARTICLE EMITTED	HALF LIFE	FORM USED	$/WATT
STRONTIUM-90	β	28 yrs	STRONTIUMTITANATE	[illegible]
CESIUM-137	β	30 yrs	CESIUM CHLORIDE	[illegible]
CERIUM-144	β(WEAK γ)	285 days	CERIUM DIOXIDE	[illegible]
PROMETHIUM-147	β(WEAK γ)	2.6 yrs	PROMETHIUM SESQUIOXIDE	[illegible]
POLONIUM-210	α(WEAK γ)	138 days	POLONIUM (ELEMENT)	[illegible]
PLUTONIUM-238	" "	86.4 yrs	PLUTONIUM CARBIDE	[illegible]
CURIUM-242	" "	162 days	CURIUM SESQUIOXIDE	[illegible]
CURIUM-244	" "	18.4 yrs	CURIUM SESQUIOXIDE	54
COBALT-60	γ, β	5.3 yrs	COBALT (METAL)	10

The illustration shows some of the radioactive elements which are currently in use or under consideration for use in the future. Some of the aspects of these radioisotopes which must be considered for optimum selection are their production costs, availability, type of particle emission (alpha or beta particles, gamma rays, X-rays), and the effect of the emission on payload components (semiconductors, man, etc.). The penetrating characteristics of the radiation govern the type, or amount of shielding necessary. These shielding requirements can greatly affect overall system weight.

One of the first attempts at using radioactive materials as a heat source was SNAP-1A. It was planned to vaporize mercury to drive a turbogenerator. Design difficulties were encountered and this project was discontinued.

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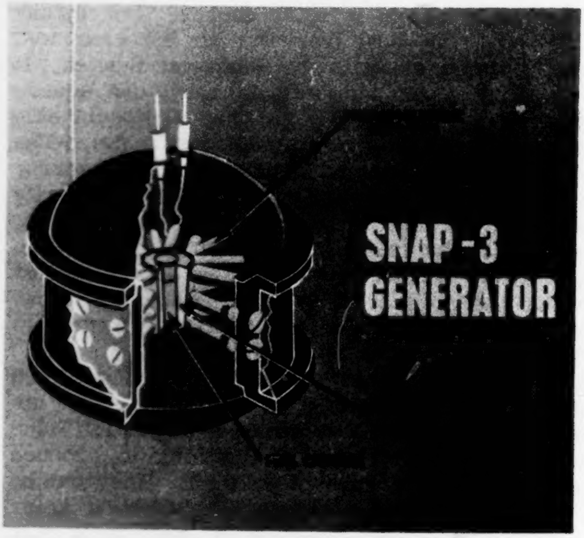
The proof of the practicality of the radioisotope power generation concept was provided by laboratory tests of SNAP-3 in January, 1959. The radioactive material used was polonium-210, and electricity was generated by thermoelectric conversion. The SNAP-3 generator was not intended for actual flight and the first application of nuclear energy in space was demonstrated with a similar device using plutonium-238. It was used as a secondary electrical power source for the instruments carried on TRANSIT-4A launched on June 29, 1961. A similar generator was used on the TRANSIT-4B Satellite in November, 1961. A larger generator, designated the SNAP-9A, was placed on two later Transit satellites. SNAP-11, a thermoelectric system with Curium-242 as the heat source, had been proposed for supplementing the solar cells for later Surveyor vehicles for soft landings of instruments on the Moon. The SNAP-11 project has been terminated, however, because of redirection of power sources for the Surveyor program.



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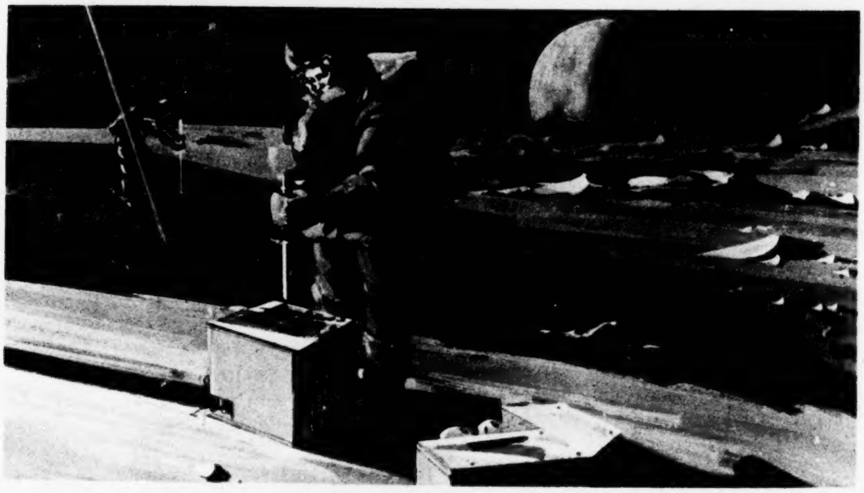

SNAP-19 units use Plutonium-238 with a unit design life of three years. SNAP-19 generators will supply about 50 Watts of electrical power to augment the large solar panels of NIMBUS-B, which provide 200 Watts.

The only power supply currently planned for use by NASA in the Apollo Lunar Surface Experiment Package (ALSEP) will be a SNAP-27 unit. It will use Plutonium-238 with a functional "Moon" life-time of one year after the astronauts return to Earth. The generator is designed so that the radioactive fuel capsule can be inserted after arrival on the Moon.

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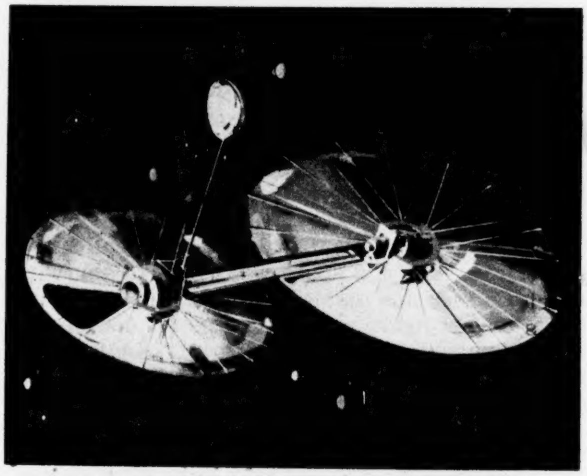
SOLAR

Another heat source somewhat removed from the space vehicle is solar energy. One means for converting heat from the Sun into electrical power under study is the Sunflower System. It would use a parabolic mirror, about 1000 square feet in area, of highly polished aluminum skin bonded to a honeycomb plastic material. The solar energy collected at the focus of the mirror would be stored as heat in lithium hydride; partly as sensible heat by increasing the temperature, and partly as latent heat of fission. A reserve supply of heat would thus be available for power when the spacecraft is in the Earth's shadow. The design power of the Sunflower System is 3 kilowatts.



Now, let's consider another means which converts solar energy to electrical power directly, namely the familiar solar cell. Solar cells use photovoltaic conversion to produce electricity from rays of sunlight. They can be connected in large numbers to form a solar array. The main advantage of solar cells lies in the fact that they do not have to carry a fuel supply since the energy is provided by the Sun. This advantage is partially offset by the large number of cells required to produce an appreciable amount of power. The quantity of electricity generated is proportional to the exposed area perpendicular to the Sun.

In some satellites, such as Earlybird, the solar cells are located essentially over the whole outside surface of the spacecraft. In others, such as Mariner and Nimbus, an array of solar cells is laid out on panels. Because of their large area, these panels are initially folded up for launching and extended when the vehicle is in space.

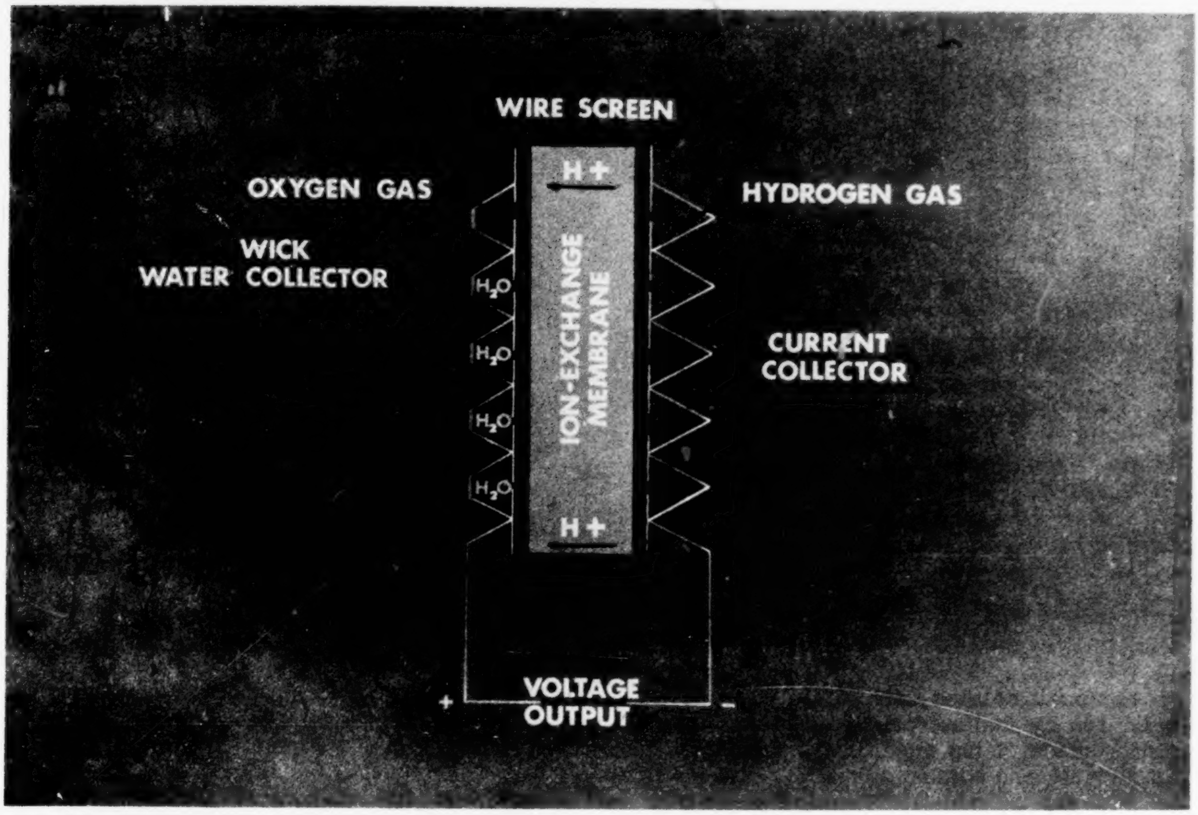
At the distance of the Earth's orbit about the Sun, the solar power available is about 130 watts per square foot of surface perpendicular to the Sun's rays. In solar cells of present design, only about 10 per cent of this energy is converted into electricity.

Another weakness of the solar cell has been the loss in effectiveness from the action of various particle or electromagnetic radiations in space. These include natural radiations as well as radiations produced by man-made nuclear explosions at high altitudes. Research is continuing to develop solar cells with greater resistance to temperature extremes and particle radiations.

BATTERIES

For present satellites which pass into the Earth's shadow at regular intervals the solar cell units are usually supplemented with chemical storage batteries. The batteries are charged when the satellite is in sunlight so that power will be available during the dark periods. Storage batteries are also included in the electrical supply system for missions into space even where sunlight is continuous. These batteries provide for the increased power demands by special instruments activated when the space probe approaches its destination. Except for the internal power required during the launch phase and for the preliminary orientation of solar cell arrays, chemical batteries do not supply energy during long space flights.

Before satisfactory solar cell arrays were developed, several of the earlier experimental satellites used primary-cell batteries as the principle source of electrical power. Manned spacecraft have also used batteries of this type. The energy is derived from chemical reactions of materials in the battery electrodes, and in the electrolyte solution. Primary cells (consisting of zinc and silver-oxide electrodes immersed in a potassium hydroxide electrolyte) were used to supply power for operating instruments and radios in the Mercury project. Such batteries are limited essentially by the quantity of active chemical materials they contain. The Mercury spacecraft were not in orbit for very long, so non-rechargeable primary batteries were adequate. For longer duration flights a new and different power supply appears necessary.



FUEL CELLS

When a supply of electricity is required for days or weeks, there is a definite weight advantage in using chemical fuel cells. Fuel cells were used in Gemini and will be used in Apollo. The energy is supplied by the chemical reaction between gaseous hydrogen and oxygen. The fuel cell for the later Gemini spacecraft was made of two woven metal wire screens, acting as electrodes, separated by a solid resin, cation-exchange membrane that served as the electrolyte. Hydrogen gas is supplied to the anode and oxygen gas to the cathode. Reactions occur leading to the transfer of protons (cations) through the electrolyte from the anode to the cathode. As a result, an electromotive force of about one volt per cell is produced. A stack of about 30 of these cells in series can cause an electric current of appreciable strength to flow through an external circuit. As an added benefit, the water formed in the chemical reaction is potable.

SUMMARY

It should be apparent to the reader that there are numerous methods of supplying power for a spacecraft. The governing factor has been, and still is, the optimization of the weight of the power unit required. The requirement for power over longer periods of time will most likely be met with nuclear reactor systems. Solar cells have good lifetimes, but they are limited in total power output. Fuel cells can produce considerable amounts of power, but they must carry their own fuel supply into space. Storage batteries undergo failures that are familiar problems to most automobile drivers. The environment of space only serves to compound these problem areas.

Today, the power supply is occupying a position of importance as a limiting factor in our conquest of space. The development of high capacity, low weight power supplies is an active frontier for the engineer-scientists of today's space age.

COMMUNICATIONS, TRACKING, AND GUIDANCE

General

Communications and other auxiliary systems which depend directly on communication for their implementation play vital roles in space exploration. Accurate tracking of a space probe vehicle is required for assessment of guidance accuracy, measurement of trajectory perturbations, and for assurance that the probe reaches its assigned objective. Most types of guidance and control systems depend on radio communications for their implementation, although optical systems are of importance. With the possible exception of recoverable vehicles, a space probe's most important function is the measurement and return of scientific data. Each vehicle may carry instrumentation for the measurement of several quantities. Many of these measurements will be of slowly varying quantities that may be telemetered on a continuous basis, or may be sampled and transmitted on an intermittent basis (along with data from other instrumentation) on a single narrow band channel. Communications systems are essential to successful space flights now and in the future.

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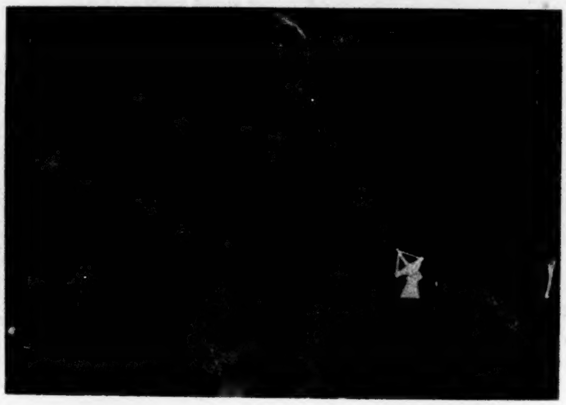
Communications

The major difference between terrestrial radio communication techniques and those necessary for space vehicles is the increased range (the mean distance to the Moon is 239,000 miles, about 1000 times the maximum line-of-sight communication range on Earth's surface). Communications with planets in the solar system will involve greater ranges by a factor of 200 to 10,000 times the Earth-Moon distance. Radio communication to the vicinity of the Moon is definitely practicable now, and extensions of the art have made possible communication to space vehicles enroute to the near planets.

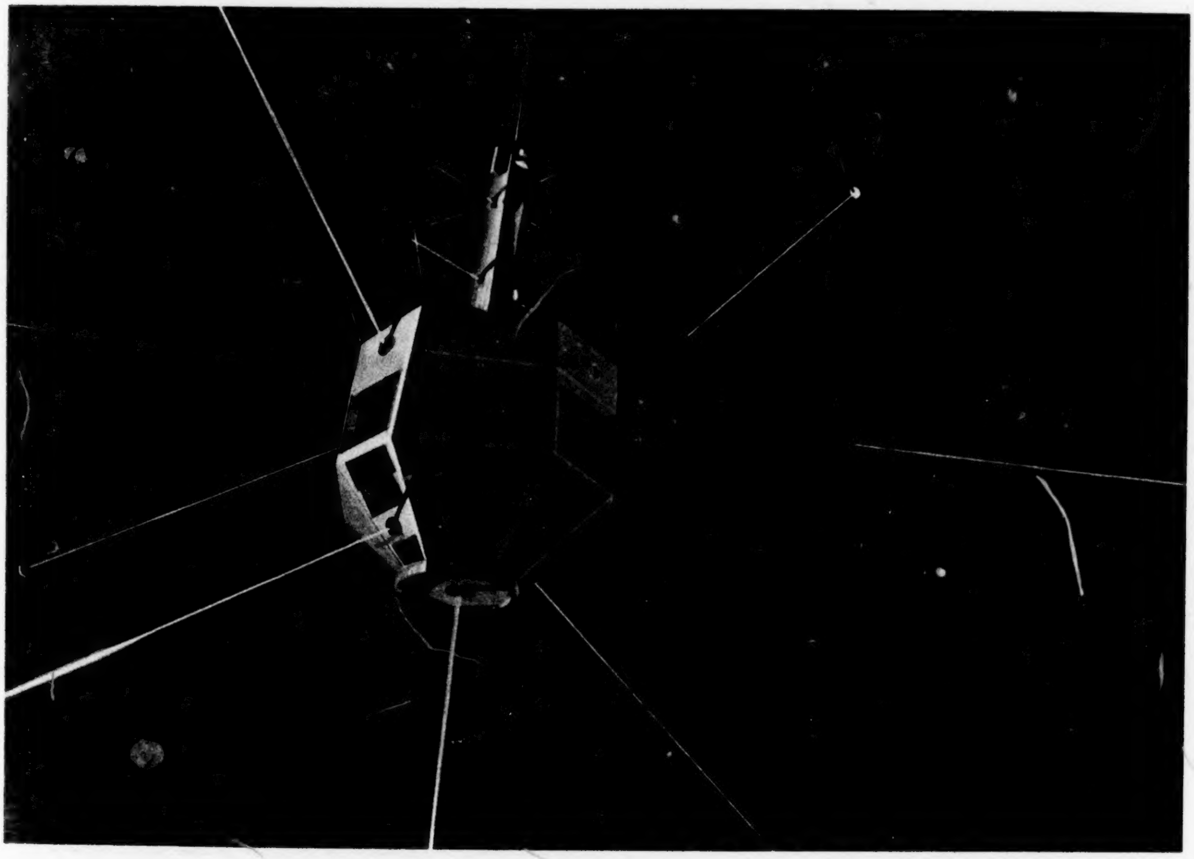


Radio Range Factors

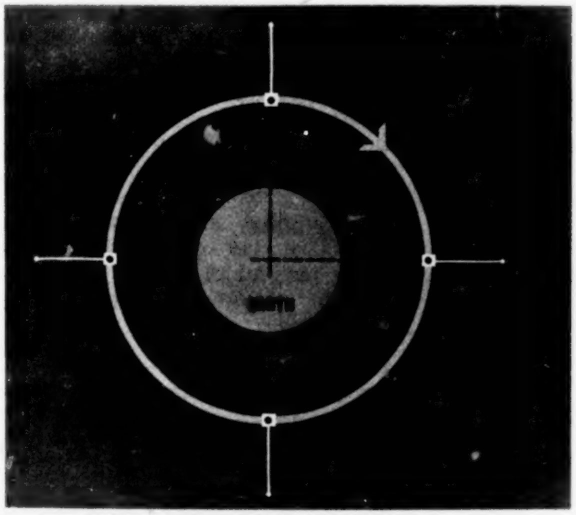
The maximum attainable range of a communication system is dependent on several factors. At the transmitter, range is a direct function of the square roots of the power and of the antenna gain (ability) to concentrate energy in a particular direction). At the receiver, range is a direct function of the wavelength as well as the square root of the antenna gain. It is also an inverse function of the square roots of the temperature, the bandwidth, and the receiver noise figure. Ultimate range is limited by external noise sources, both man-made and natural. Let us discuss these parameters affecting radio range in more detail.

The power of Earth-based transmitters is limited only by the state of the art and by economics. Earth-based transmitter power outputs which can average thousands of kilowatts and peak at tens of megawatts are in operation.

The gain of an antenna is primarily a function of its size. At Earth-based transmitter or receiver stations, very large antennas (high gains) are practical, limited principally by economic factors. Other limiting factors may be the mechanical accuracy to which large area structures can be pointed, the practical tracking or slewing rates, and the knowledge of the location of the space vehicle with respect to the Earth-based station. On space vehicles practical antenna sizes and gains are severely limited by weight considerations and by the mechanical problems of unfolding the structure from its launch configuration to its operating configuration. Another factor which will limit a vehicle's achievable antenna gain is the accuracy to which it will be practical to stabilize the antenna in space. Since a stable antenna can function with a narrower beam of energy and hence higher gain, a satellite designer must decide on what attitude stabilization he will use before choosing an antenna or power supply.



Spin Stabilization, where the satellite spins about one of its axes to prevent tumbling, appears one of the more frequent choices for communications satellite design. Control of the spin-axis direction, maintained perpendicular to the orbit plane, can be done with a jet pulsed precisely in synchronism with the spin. This technique has been used with many successful communication satellites (Syncom, Early Bird, and the Intelsat II series). Overall temperature control is much less a problem with spin stabilization because the solar effects are averaged over spinning surfaces.



Gravity-Gradient Stabilization (GGS) uses the variation in gravitational attraction with distance to align a body with its "long-axis" (or axis of minimum moment of inertia) pointing toward the Earth as will be discussed thoroughly in Chapter Fourteen. Because of technical considerations (inconsistency of the Earth's magnetic field, for example) the altitude region around 6,000 nautical miles appears suitable for GGS. However, the GGS technique is under investigation for synchronous altitude (22,300 miles) by both the Department of Defense Gravity Experiment (DODGE) and NASA's Applications Technology Satellites.

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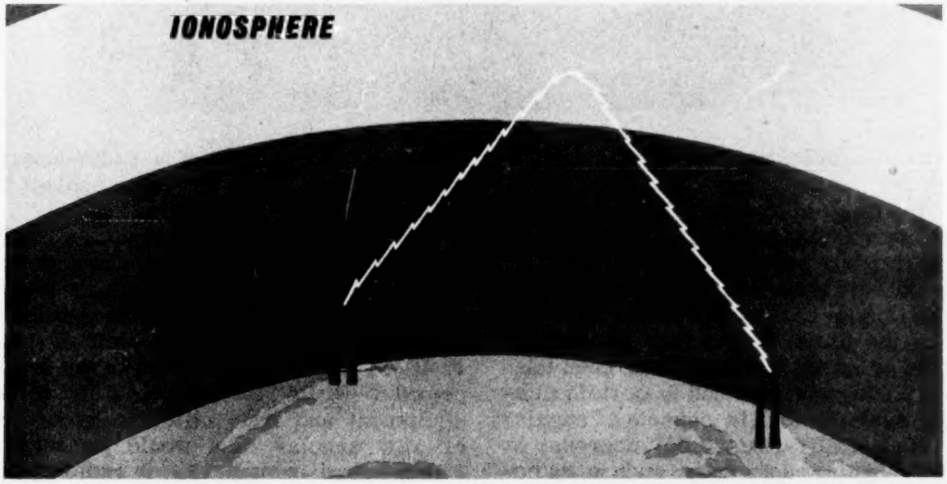

The choices of wavelength for a space communication link are limited to the range of wavelengths which will pass through the Earth's atmospheric shell with negligible absorption or refraction. Wavelengths shorter than about three centimeters would suffer appreciable absorption by atmospheric gases and moisture. Wavelengths longer than about three meters will be refracted by an amount which will depend on the angle of incidence and on the degree of ionization and thickness of Earth's ionospheric layers. Radio propagation conditions in space itself are otherwise ideal, due to the absence of absorption and refraction phenomena which make long distance communication around Earth so difficult.

The bandwidth of a communications channel must be compatible with the information rate which is to be transmitted. Since range is an inverse function of the square root of bandwidth, it is clear that bandwidths must be reduced by all practical means, such as coding of data to eliminate redundancy, or by storage and readout over an extended time. Narrow-banding receiver techniques are a valuable means for increasing receiver ranges, provided total system bandwidths are limited to a few kilocycles.

External noise sources include man-made interference, which can be controlled within acceptable levels by careful choice of receiver site and by filtering and shielding. Natural radio noise sources are the Sun, galactic sources, and extra-galactic sources. The Sun is normally a very low-level noise source for an omnidirectional receiving antenna and will be a still lower-level source for a directional antenna provided the main beam or a major side lobe is not directed toward it. During periods of intense sun-spot activity noise bursts commonly cause peak radio noise of 100 to 1000 times the normal level. In general, galactic and extra-galactic noise sources are below the levels that will interfere with space communication in the present state of the art.

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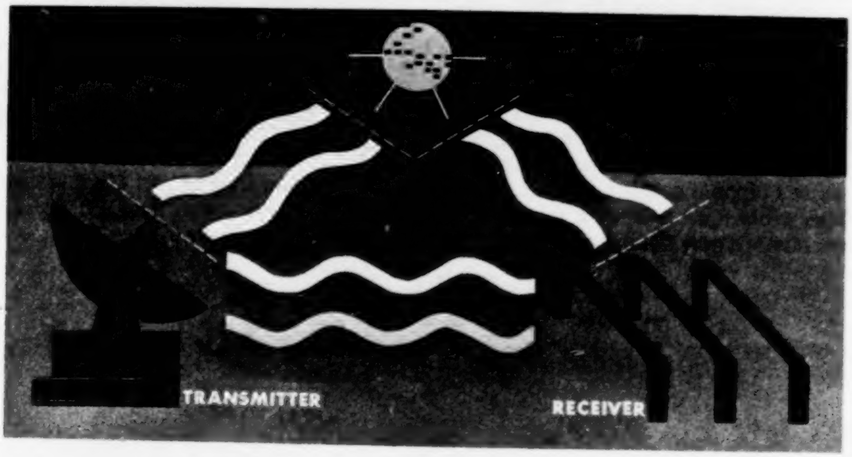


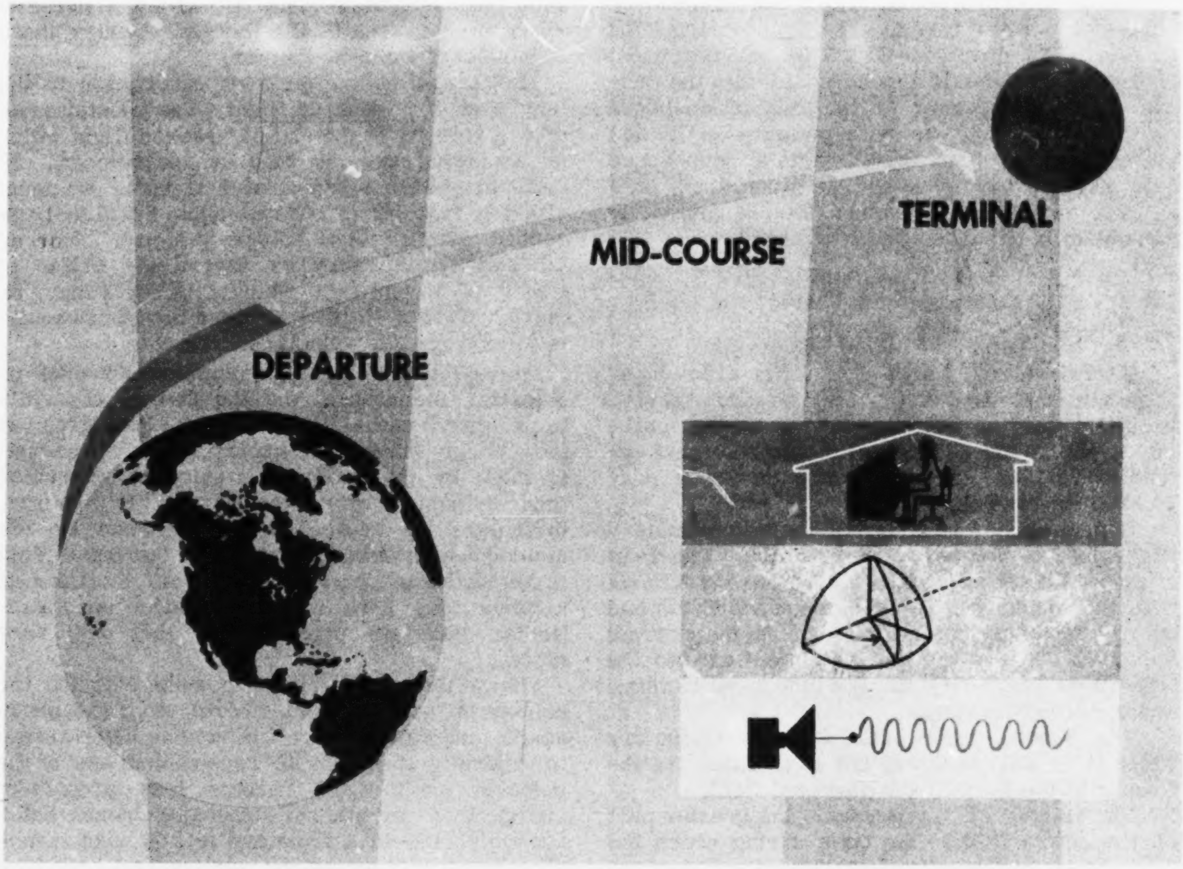
Tracking

Angular tracking of space vehicles can be accomplished by reception of stable telemetering signals on four fixed antennas located at known separations on two base lines meeting at right angles. The angle of arrival of the signal is a function of the phase differences of the four signals. This tracking principle has been used in satellite tracking systems and in certain missile tracking systems and is capable of angular accuracies of 1 milliradian (0.057 degrees) or better. The angular data from such a radio-interferometer tracking system will be subject to corrections for refractions suffered by the signal in passing through the Earth's ionospheric layers. These corrections can be estimated from meteorological and angle-of-arrival data.

A radar-transponder system which provides both angle and range data (similar to those developed for certain missile guidance systems) is used in some space vehicle tracking. This type of tracking system gives angular accuracies at least equal to those of a radio-interferometer system. This system is also subject to corrections for ionospheric refractions.

At interplanetary ranges, a radio-optical tracking system using vehicle-determined data may be preferred. The space vehicle would carry optical trackers which would determine the angular position of the vehicle with respect to three celestial bodies of known orbits. Space position would be computed by vehicle-borne equipment and transmitted to ground receivers, or raw angular data would be transmitted to Earth-based computers. A radio-optical tracking system would not be subject to ionospheric refraction errors, and positional accuracy would not be a function of the Earth-to-vehicle range.

Optical tracking from Earth-based observatories is possible with the aid of vehicle-borne inflatable balloons, flash powder bombs or visible chemicals. Although special sighting yields very accurate tracking results, its success is dependent on the existing contrast and visibility conditions.



Guidance and Control

For the mere peacetime exploration of circumterrestrial space, ground tracking of the vehicle should be sufficient, and precise guidance on any particular trajectory is not a critical necessity. However, the performance of any astronautical mission to a lunar or planetary destination is a tricky high-speed interception problem. The guidance requirements are severe and depend a great deal on the method of propulsion, notably whether it is entirely impulsive, followed by a long uncontrolled coasting phase, or whether means are provided for midcourse and/or terminal correction by short vector bursts of high-acceleration, or long periods of low-acceleration and deceleration.

In the case of the trajectory which is essentially ballistic, the initial guidance is of critical importance. The choice of the impulsive departure velocity then largely determines not only the travel time, but also the "aiming" accuracy requirements. In general, if the departure velocity is barely sufficient to reach the orbit of the target body, the magnitude of the velocity has to be held to extreme accuracy, because even errors of the order of one in 10,000 would cause a large over or undershoot. On the other hand, if the trip is made at a slightly faster velocity, the velocity tolerance can be relaxed. The angular aiming tolerance, however, tightens up as the velocity is increased. For lunar missions this problem has been treated in considerable detail. Available radar methods in conjunction with advanced autopilots appear quite adequate for lunar intercept missions.

Navigation between Earth and Moon has been successfully demonstrated by Ranger, Surveyor, and Lunar Orbiters. Earth-based tracking of a cooperative transponder aboard the spacecraft provided information on which the midcourse corrections were based. The Apollo navigation system was initially designed to be independent of this type of ground tracking, although the concept is swinging now to the use of on-board navigation as back-up with primary navigation information coming from Earth's deep-space network. Between here and the Moon, then, let's set the navigation problem aside, as primarily a problem in ground-based tracking.

Interplanetary Travel

Interplanetary travel will differ from lunar flights in that the vehicle may be considered to escape from the influence of the Earth; unlike the flight to the Moon, where gravitational attraction of the Earth and Moon must be considered for the entire flight.

For analysis, let's break the interplanetary flight into a number of segments. The first of these, the boost phase, or powered flight, deals with the orbit while it is close to the Earth and energy is being applied to achieve the correct velocity. This phase ends at injection into the free-flight trajectory as was discussed in detail under Astrodynamics.

The second phase deals with the trajectory while it is still coasting but still under the influence of the Earth's gravitational field.

The third portion represents the greater part of the entire flight - the time during which the spacecraft is subject only to the influence of the Sun's gravitational pull.

As we near the target planet, we enter still another phase, in which we must consider the gravitational effect of the destination planet. And, finally, we deal with the very last few minutes of flight while the spacecraft is in the planet's atmosphere.

Each portion of the trajectory has its own specific navigation problems. The first, or boost phase must be controlled by some form of command guidance, due to the critical timing factors involved, and the vibration and g-forces imposed on the astronauts. This control has been demonstrated many times by successful space flights. The final atmospheric entry phase is subject of the next chapter

Let's confine our present description to the long span of midcourse flight. The booster must give a velocity at the end of powered flight which is somewhat greater than escape velocity. In fact, to perform any useful transfer we must attain a velocity at burnout about 8,000 feet per second greater than escape velocity. Such an increment can carry us toward the orbits of either of the planets nearest to us, Venus, or Mars. Travel to planets other than these would require a greater velocity increment.

Interplanetary space navigation depends on celestial mechanics and the theory of orbits in a gravitational field because the greatest part of the work in transporting the spacecraft is done by the action of gravity forces rather than by spacecraft propulsion. In essence, interplanetary travel is accomplished by becoming an artificial satellite of the Sun. This is far different from driving a car or flying an airplane, for once we have started on a particular path we cannot alter that path very much.

Since there are infinite possibilities for the choice of a path from "here" to "there" in space, and since "there" is moving with respect to "here", it stands to reason that one of the possible paths will require less propulsive energy than the others. Choosing launch dates for which the interplanetary trip is most favorable reduces this energy requirement even further. We call this optimum path a minimum energy trajectory. We will want to stay fairly near this path in order to carry maximum payload. Should we be willing to sacrifice payload for a faster trip by choosing a higher energy trajectory, we encounter a more difficult entry into the atmosphere of the target planet due to the higher velocity of arrival.

These are the factors, then which force us to wait out the 584 days between favorable launch times for a trip to Venus, and 780 days between sending flights to Mars. We do it to remain near the minimum energy path.

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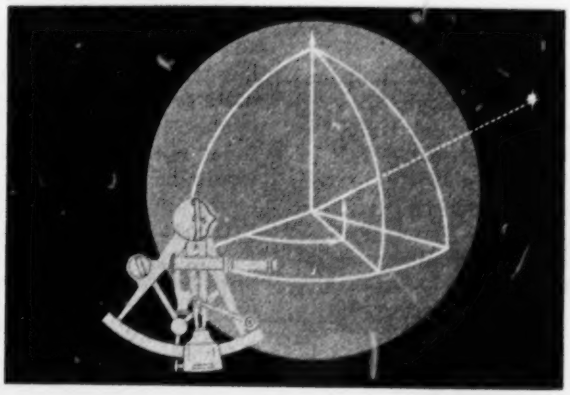


Navigation Equipment

With the path of our travel defined before leaving the Earth, the next concern we have is the choice between a self-contained navigation system for the spacecraft, or a dependence on Earth-based tracking such as that used in the Ranger and Mariner missions.

Our definition of a self-contained system would include inertial components employing gyroscopes and accelerometers, and also equipment for optical tracking of the stars and planets. Doppler radar would also be included.

Making the spacecraft the point of origin for our navigational measurements simplifies the methods and computations necessary to fix spacecraft position. But at the same time, the quality of performance of on-board equipment is limited by the permissible size and weight. Weighed one against the other, the comparison appears to favor the use of on-board equipment when the spacecraft is at great distances from the Earth. In the final phases of a flight to Venus, when the spacecraft is a million miles from the destination planet, it is more than a hundred million miles from the Earth. We can live with considerably less precision in our on-board system than by depending upon far off observers on Earth.

The on-board navigation equipment must be capable of giving five basic measurements: celestial angles, celestial distances, vehicular velocity, vehicular acceleration, and time.

For measuring angles, satisfactory equipment is already available. Planet tracking telescopes exist with accuracy of one second of arc. (At 50 million miles, one second of arc would give a cross-sectional uncertainty of 250 miles).

Celestial distances to the nearer bodies can be obtained directly from stadimetric equipment, radar, or from comparing the known distance between two bodies with the apparent distance between them.

Velocity can be determined within 1% by several means, such as plotting several successive radar fixes as a function of time, from a direct readout of the Doppler radar, or from the integrated output of the accelerometers. Currently available accelerometers are adequate for measuring accelerations imposed on a spacecraft. For all but the most simplified systems, these are mounted on a gimballed, inertial platform.

Finally, time can be measured to one part in 10^5 by conventional chronometers, but these are too delicate for our long duration space flight. Clocks based upon atomic vibrations are well along in development, with accuracies of one part in 10^8, but so far these are too bulky. The best compromise right now appears to be the quartz crystal clock, giving time measurements accurate to one part in 10^5.

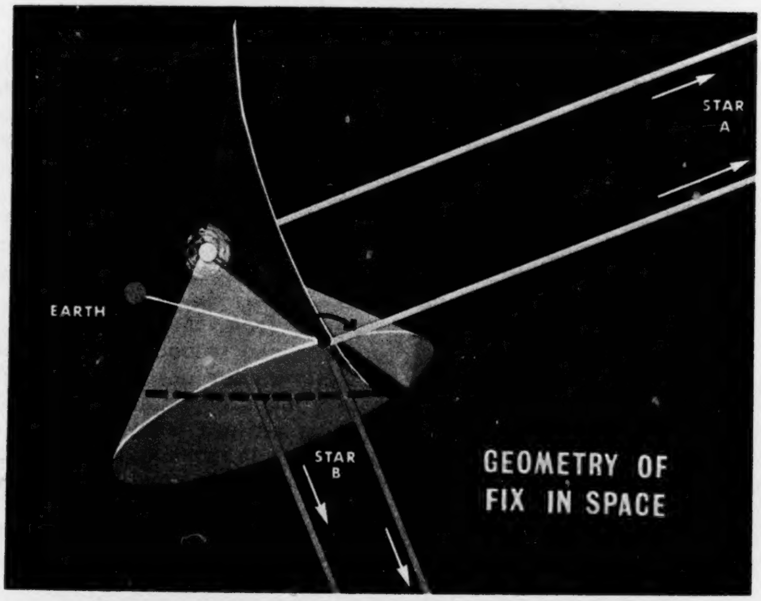
Having made the necessary measurements, one must correlate the information into a useable form. This will require a small but versatile computer to resolve the inputs, to provide deviations from the nominal trajectory, predict position and velocity, and to calculate required velocity vector changes. In addition, the computer must determine spacecraft attitude and provide attitude control signals during thrusting periods. It must signal the existence of abort conditions, and must provide information on a continuing basis to a command display system. How large a computer is necessary? The computers for Gemini and Apollo occupy a space of about one cubic foot.

Navigation Methods

Consider now the geometry of a fix in space. The first step is to measure the angle between our line-of-sight to a star and to a near body, the Sun. This measurement places out spacecraft on the surface of an imaginary cone whose apex is the Sun. The axis of the cone has the direction of the line-of-sight to the star. The star is so far away that its direction of its incoming parallel light is independent of the point of observation.

Now we repeat the process, using a second star and the same near body. A second cone of position results, having a different axis and apex angle. The two cones intersect in two straight lines, one of which is the line of position of the spacecraft. A third star measurement made with respect to the same near body would distinguish between the two lines of position already determined, but would otherwise provide no new information. (Generally, the two lines of position are so widely separated that an approximate knowledge of the spacecraft position resolves the ambiguity).

There are several ways one can determine the actual position of the spacecraft along the line of position using a near body in addition to the Sun: (1) measure the apparent diameter of a nearby planet, or (2) measure the angle between sight lines to two near bodies, or (3) compare the apparent distance between them to the actual distance. Most of these techniques require computers and complex electronic devices. As discussed in the Navy's Space Navigation Handbook, NAVPERS No. 92988, navigation for cislunar space is based upon a simple method which would be independent of Earth Tracking support. Using this concept during return to Earth, an astronaut, out in space and looking down at the Earth, is looking down his local vertical. If a star happens to be conveniently located in front on the other end of this vertical line, he can, by reference to a set of tables, determine the position of the line in space. Then, by using stadimetric techniques (similar to shipboard stationkeeping methods where one compares apparent to real) he can measure the apparent diameter of the Earth's disc, and from this measurement determine range. This diameter is an easily measured quantity: at a range of 25,000 miles out the Earth's disc subtends an angle of 15 degrees. Of course, there won't always be a star conveniently located on the local vertical, but to answer this problem the same techniques could be used to establish the line of position from observations of known stars behind the Earth, out to a semi-diameter away from the edge of the Earth's disc. He can thus prepare for the most critical phase of any space journey: the final landing on terra firma which we will discuss in the next chapter.



CHAPTER 9

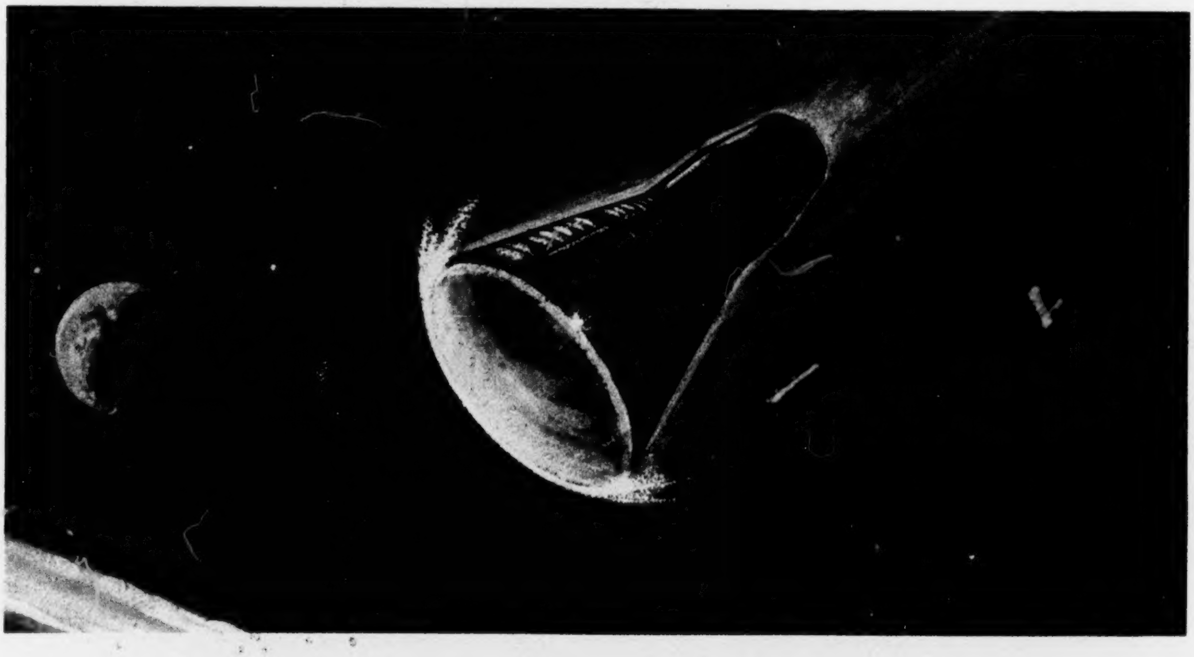
ATMOSPHERIC ENTRY

GENERAL

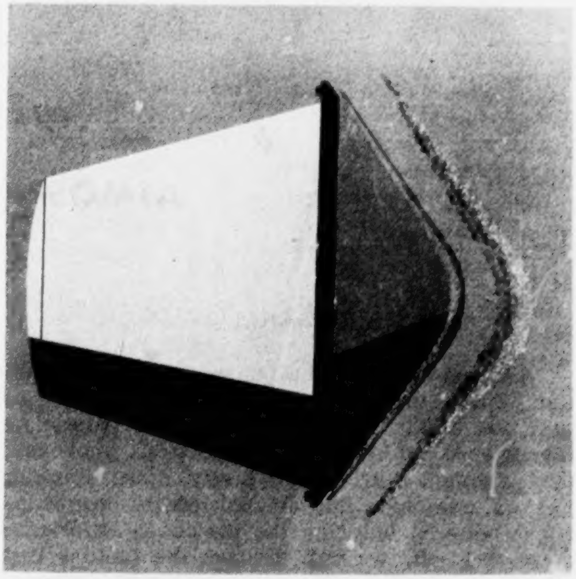
Although launches into space are almost routine today, the challenge of returning men or payloads safely to Earth will always exist. As the speeds of returning spacecraft increase, the problems will become still more critical. Let us examine this crucial period in spaceflight between entering the air ocean and touchdown. First, we will discuss the factors that determine a safe landing. After discussing these, we will review the development of vehicles that make controlled descents, and then briefly discuss spacecraft of the future.

The sensible atmosphere of the Earth which will generate frictional heat extends outward to about 100 miles. In returning from space, a spacecraft encounters this atmosphere and must face two extremely critical conditions: deceleration and heat caused by friction. As a vehicle slows during descent, it reduces its kinetic and potential energy by transferring energy to heat the surrounding air, but some of this heat is transferred back to the vehicle's surface. For example, at 17,500 miles per hour, the kinetic energy of a moving body is equivalent to about 13,500 BTU of heat for every pound of the vehicle's weight. Converting this kinetic energy to heat upon reentry provides more than enough heat to vaporize everything in the craft! Our primary concern, however, is only that fraction of heat generated that is absorbed by the vehicle.

The amount of energy absorbed is determined by the vehicle's shape, velocity, altitude, and exposure time; but more fundamentally by the mechanisms of heat transfer between the hot atmospheric gases and the materials of the vehicle's surface.



DECELERATION AND HEATING



Aerodynamic profiles (the shape of the spacecraft) principally determine the deceleration of a returning vehicle. Blunt configurations, such as our manned Mercury and Gemini space capsules, have certain advantages during atmospheric entry. Any blunt object traveling at high speed is preceded by a strong shock wave that extends a considerable distance around and ahead of the object in the surrounding gases. This shock wave diverts heat away from the body because the colliding gas molecules are pushed away from the vehicle's surface. The stronger the shock wave, the larger the fraction of the total heat load that is transferred to the surrounding atmosphere and the smaller the amount of frictional heat absorbed by the vehicle. In the case of the Mercury capsule, about 99 percent of the heat energy was diverted by shock wave action. The heat that does reach the vehicle is transferred from the shock wave mainly be radiation. Because of its high resistance (shape), a blunt object will decelerate more rapidly after entering the atmosphere than a slender configuration so a shallow entry angle must be chosen to offset the hazardous g-stresses and excessive heating caused by entering the denser air too rapidly. Hence a blunt body must be programmed to enter at a gentle angle (abo 2 degrees) to experience lesser deceleration forces (usually less than six g's). The price paid for this maneuver is exposure to heating for a longer period which increases the total heat load.

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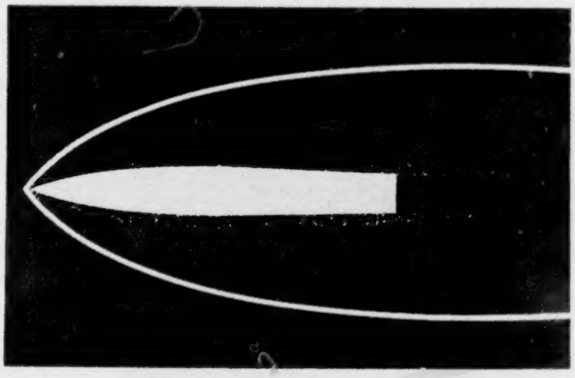

Slender configurations, on the other hand, tend to be less effected by "back" radiation from the shock wave because of their smaller frontal stagnation area and the higher sweep of the bow shock wave. A ballistic missile, for example, can decelerate at about 65 g's without excessive heat damage as it penetrates the atmosphere at angles near twenty degrees from the horizontal. This deceleration is equivalent to stopping a car going 60 miles per hour in only 2-feet of space! Naturally, manned spacecraft cannot sustain these high g-stresses even if they must go to greater efforts to dissipate the increased heat load occasioned by "gentle" descents.

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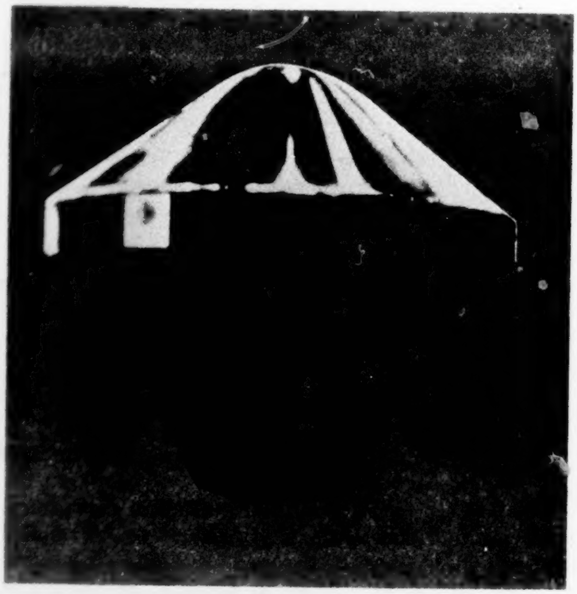
COOLING TECHNIQUES

Now that we've specified the entry problem, let's briefly examine some of the more widely known cooling techniques that can be employed to minimize frictional heating or solve the thermal part of the problem. The most common cooling methods are conduction, ablation, transpiration, regeneration, radiation, and possible combinations of these cooling methods.

Conduction of heat away from a hot-spot in the vehicle by a material of high thermal conductivity and a large heat capacity is called the conductive heat-sink method of cooling. Either a solid or liquid heat-sink may be used. In addition to the high thermal conductivity and large heat capacity, it is desirable for a solid material to have a high-melting temperature, high reflectivity, and a low surface temperature gradient (heat spreads evenly). Copper is a very good heat-sink material because of its high thermal conductivity. Although very heavy, it was selected as surface material for the first ballistic missile reentry vehicle, mainly because of its favorable high thermal conductivity. In addition to its weight disadvantage, copper also has a comparatively low melting point. However, if the time-rate of heating of the surface is sufficiently low, the high thermal conductivity of copper will allow the heat to be conducted away fast enough so that the conductor does not melt.



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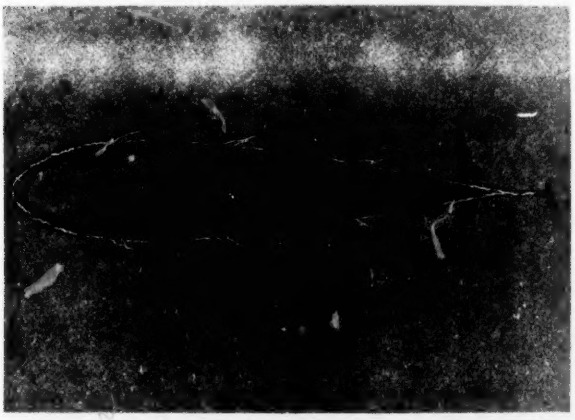
Ablation means to carry away; in our case, to carry away heat. Ablative material wears away as a result of friction of air moving past it at high speeds. The material first forms a foam, chars, and then vaporizes as it flakes off. The process of ablation dissipates a good deal of heat in vaporizing, and further heat protection is provided because the vaporized material tends to block the conductive flow of heat from the shock layer into the vehicle. Materials such as pyrolytic graphite, avcoite, and phenolic resin are currently used as ablatives on missiles and spacecraft.

The use of a blunt-nosed reentry vehicle with an ablative heat shield is currently the most popular entry cooling method. Although it is the lightest and perhaps the simplest solution of the reentry problem, it is less than optimum, especially for manned vehicles. This particular approach has several undesirable features: programmed deceleration stresses the limits of human tolerance, and the requirement of a very flat entry path into the atmosphere leads to a sizeable uncertainty in the point of impact. Without aerodynamic controls the astronauts must hazard the discomforts and dangers of a parachute landing.



Transpiration cooling consists of a system, similar to action of the human skin, through which a fluid flows through pore-like holes in the vehicle's surface. As the fluid passes through the pores, it cools the vehicle by contact. Furthermore, the fluid flowing over the surface forms an insulating layer between the vehicle and the hot air. There are two major problems associated with this principle: the fine pores must be kept from plugging to assure proper flow, and the rate of coolant flow must match the rate at which heat is generated near the surface. Any plugging or mismatch will cause a hot spot to occur that may melt the skin of the vehicle. Research is continuing to solve these problems.

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In regenerative cooling, a fluid is circulated through tubes beneath the surface to be cooled and is then passed through a heat exchanger to dissipate heat. This is similar to the cooling system of a home refrigerator. Liquid metals as well as other refrigerants can serve as the coolant.

Radiation cooling occurs to a certain degree with each of the aforementioned methods of thermal protection. The technique simply involves heat dissipation by a radiation shield to protect the body against excessive temperatures. The use of special materials as a heat-absorbing, heat-radiating shield offers certain advantages. One is simplicity. Another is that the radiation shield itself forms part of the structure of the vehicle and thereby provides a functional use besides cooling without adding to the overall weight. Radiation is the primary method of cooling in space. It can also serve as a method of cooling during atmospheric entry.

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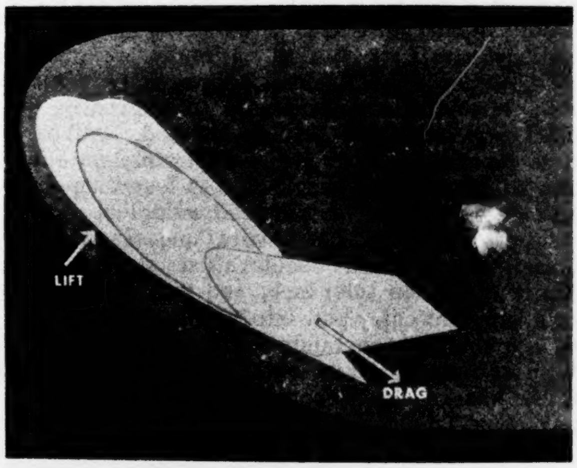
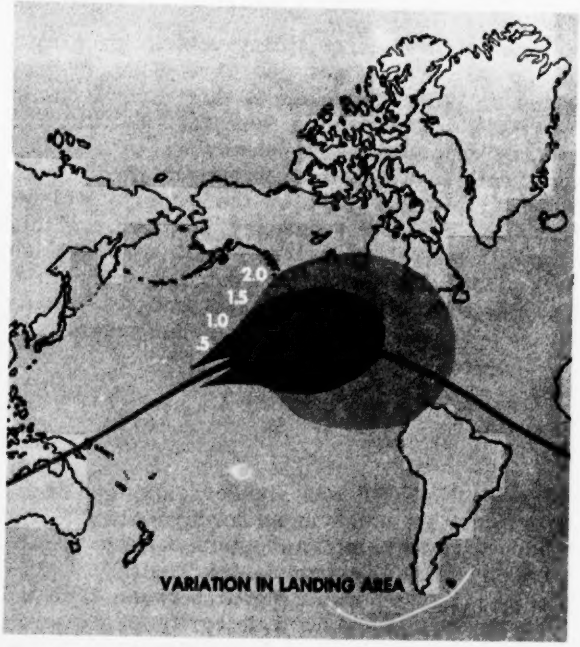


MANEUVERS

Now that we have briefly explored aerodynamic profiles and protective cooling systems, let us examine the final phase of successful spacecraft recovery, the landing operation.

The primary requirement for a manned entry vehicle is to provide sufficient lift or power to maneuver into a usable entry corridor upon return to Earth. The term "entry corridor" refers to a range of permissible three dimensional flight path conditions that will permit safe entry and landing of a vehicle. These conditions are determined by the size and gravitational fields of the planet being approached, its atmospheric conditions, the approach velocity, and the aerodynamic characteristics of the vehicle.

The performance of a re-entry vehicle depends on its "L over D", the ratio of its Lift to its Drag. Lift is the force developed which is useful to maintain and control flight. Drag is the retarding force acting to oppose the flight. The advantage that an increased L/D ratio provides is quite noticeable when we compare the present APOLLO footprint (potential landing area) obtained with a L/D ratio of 0.3 to that of a lifting vehicle with an L/D ratio of 2. When the APOLLO enters the atmosphere, it has little option as to its landing site. On the other hand a lifting spacecraft with L/D of 2 could select a landing site anywhere on one-third of the Earth's surface. The vehicle would also have some maneuvering capability near a landing field. This capability to land on a comparatively small, preselected area would decrease the expense of space operations enormously by eliminating the current necessity for worldwide recovery operations and deployment of thousands of men, ships, and aircraft. Project costs could be reduced substantially by re-using recovered space vehicles.



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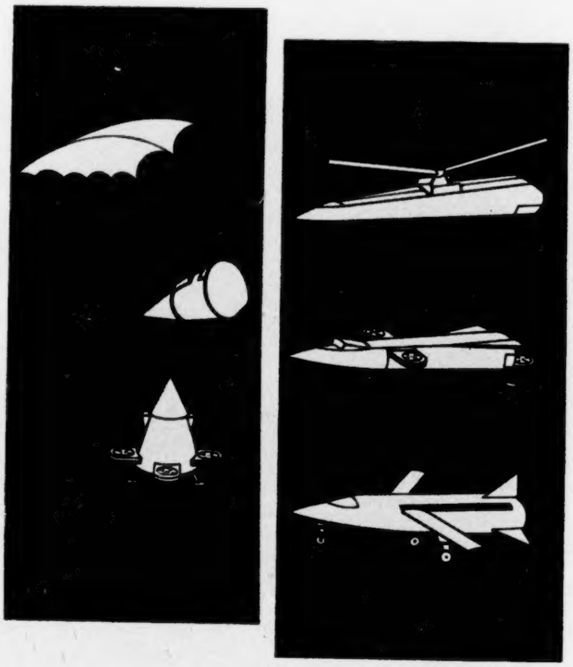
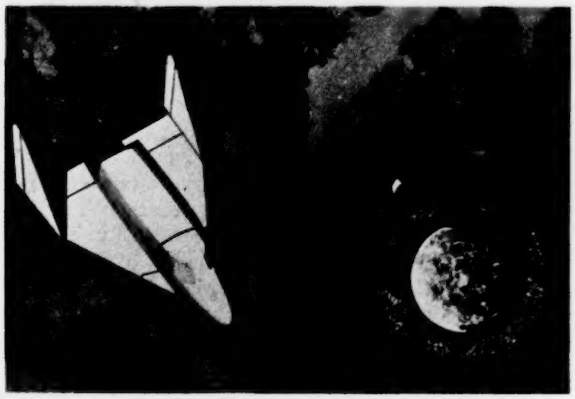
Landing modes currently under study include the use of the para-wing, para-sail, rotor, propulsive lift, and variable geometry vehicles. All achieve L/D ratios greater than current space modules. The increase in L/D ratio is usually obtained by the design shape of the vehicle.

Slender, low-drag shapes that result from attempts to improve the low-speed characteristics of the re-entry vehicles (without compromising their hypersonic characteristics) do have certain disadvantages. The first is absorption by the spacecraft of a greater total heat load. Since slim-shaped vehicles produce weak shock waves, they themselves must take up a larger part of the heat produced in deceleration. With an L/D of 2.0 for example, a vehicle must accept 10 to 15 times more heat per pound than a blunt-nosed model. A second penalty is the increased weight which results partly from the structural requirements of a long, thin shape and partly from the larger amount of heat-dissipation equipment required. However, despite these disadvantages, the advantages of controlled landing have generated great interest in the design of special lifting bodies.



PROJECT STATUS

One of the early lifting-vehicle programs of the Air Force was the Dyna-Soar Project begun in 1959. The name is short for "dynamic soaring". The vehicle was designed to glide at very high speeds in a near orbital path around the Earth in which the centrifugal effect would support a major part of the glider's weight. Some lift would be necessary, however, and this added lift involves weight penalties to provide heat dissipation and flight control mechanisms. Technical problems, plus redirection of space efforts, caused cancellation of the program in 1963.



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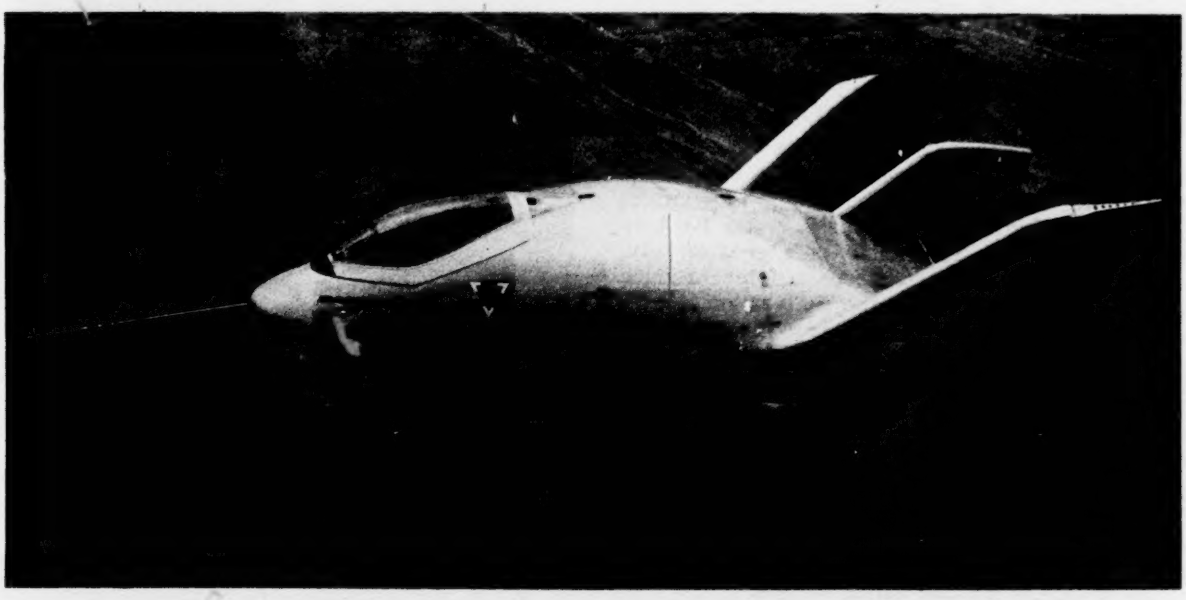
Project ASSET was another early Air Force Program. Its name is an acronym standing for "Aerothermodynamic/Aerothermoelastic Structural Systems Environmental Test". ASSET included six unmanned flights between 1963 and 1965 to test structural integrity of re-entry bodies; one of which was retrieved from the Atlantic for further study.

In 1964 the Department of Defense initiated an overall technological program in re-entry techniques called project START which stands for "Spacecraft Technology and Advanced Reentry Test". The START Program included ASSET as its first phase and then two other programs:- phase two - PRIME (Precision Recovery Including Maneuvering Entry), and phase three - PILOT, (Piloted Low-Speed Test). The three PRIME vehicles (designated SV-5D) were launched on ATLAS SLV-3's from Vandenberg Air Force Base into the Pacific Ocean landing near Kwajalein Atoll. The first flight occurred in December 1966, and the last in April 1967. The SV-5D trajectories ended at speeds of about Mach 2, when a baloon-parachute (ballute) and other parachutes deployed so a C-130 could conduct an air-snatch recovery.



The PILOT Project (phase three part of START) received funding in 1966 and is now assigned to the Aeronautical Systems Division of the Air Force. PILOT will complete investigation of the regime from altitudes of 100,000 feet and Mach 2 speeds down to landing. This test region was not covered by PRIME. A single X-24A craft for PILOT will be delivered to Edwards Air Force Base during the latter part of 1967. At Edwards, this X-24A was to join two other NASA re-entry configurations, the M2-F2 and the HL-10. Both of these NASA spacecraft had been successfully glide-tested from 45,000 feet and, like the X-24A, were both designed to carry the XLR-11 (an 8,000-lb-thrust rocket for auxiliary control power). However, the M2-F2 crashed during final approach on 10 May 1967.

Internal sub-systems of the three unusual spacecraft are much alike; each is fitted with a T-39 aircraft nose landing gear, F-5 main gears, and modified X-24A ejection seats. The 5,000-lb aluminum X-24A has two lower flaps on its boattail, and two upper flaps which, when deflected symmetrically, provide roll control. Split rudders on each of the outboard vertical fins provide yaw and directional control. In profile, the SV-5P has a cambered bottom surface and a unique, highly arched upper surface. It has a hypersonic L/D of 1.4 and a subsonic L/D of 4.5.

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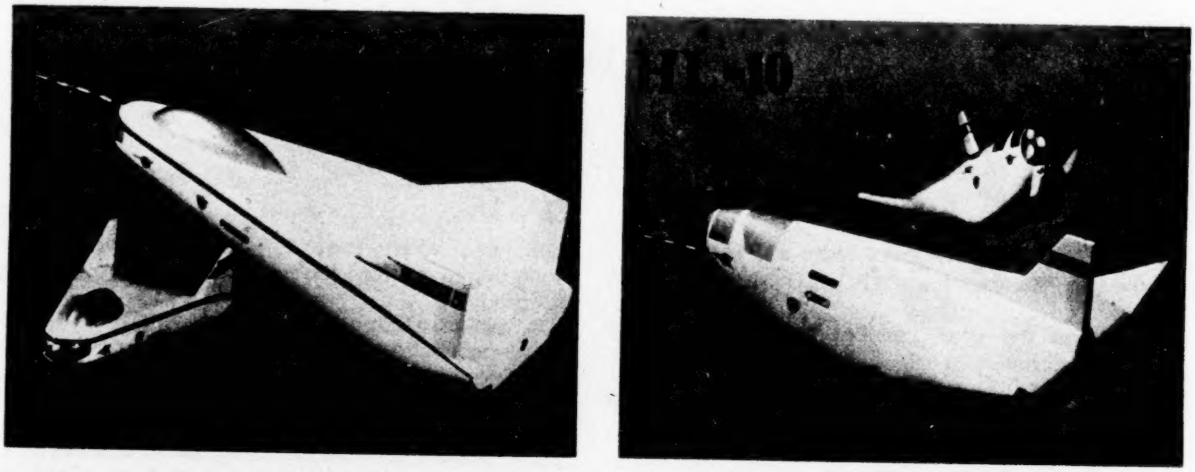
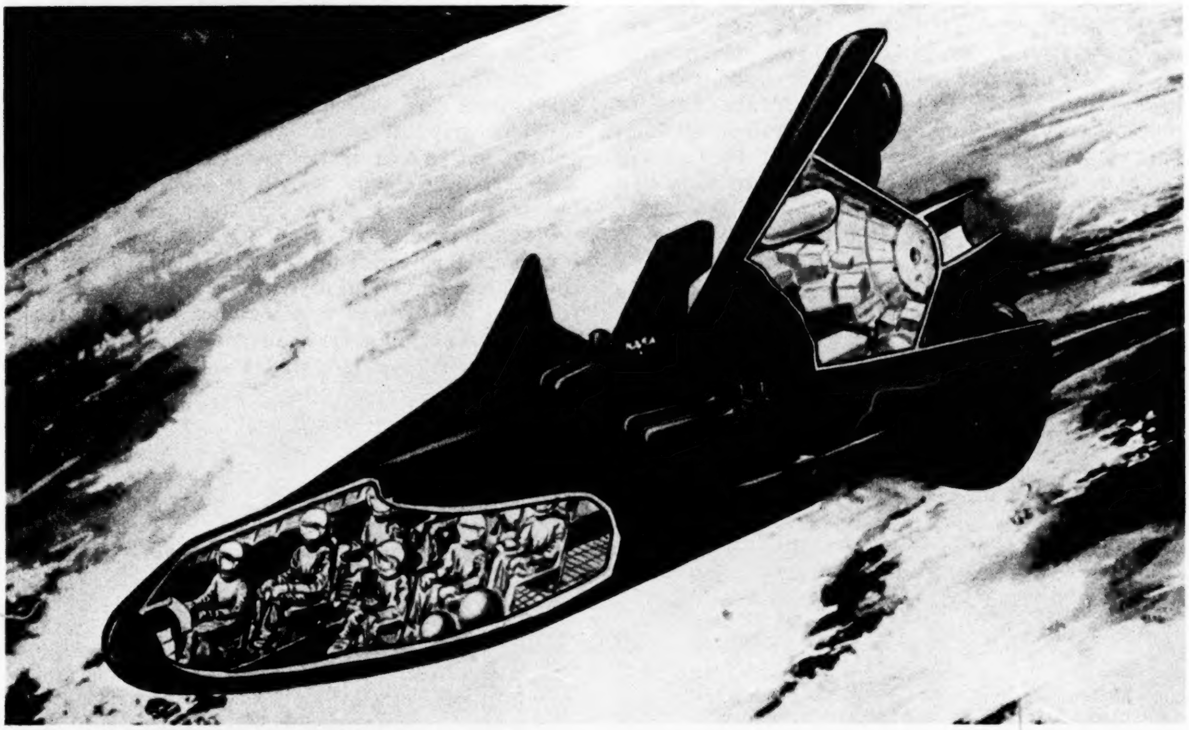


Both the M2-F2 and the HL-10 configurations have fewer control surfaces than the X-24A. The HL-10 and X-24A will both be power-tested to speeds of Mach 2 at altitudes of almost 85,000 feet during 1967. Testing of these vehicles will be conducted at Edwards Air Force Base, California.

FUTURE

While we have mentioned some of the problems and methods of atmospheric entry, several questions still remain. Their speedy solution through new designs and advanced concepts is a priority field for space research. Much experimentation must be done if breakthroughs are to be achieved. At the moment, specific studies are examining the possibility of mounting an X-24A on a Titan booster, using it as a test vehicle for an eastward flight from Cape Kennedy to Edwards Air Force



Base, and manned re-entry tests are under consideration within the APOLLO Applications Program.

Perhaps the next generation in hypersonic lifting vehicles will be a spacecraft launched from a re-usable air-breathing booster at Mach 16. Suggestions have been made to launch the X-15 at supersonic speeds from the XB-70. As a further step, the X-15 (#2 model) has been modified with external tanks to enable it to reach speeds of Mach 8. An even bigger step will soon be taken toward advancing hypersonic technology using the new delta-wing X-15 (#3 model).

Although all technological trade-offs between power-controlled versus aerodynamic-controlled landings have not been fully calculated, it appears that the powered, lifting vehicle promises a future spacecraft with broad capabilities - as a manned space vehicle for satellite inspection and repair, for crew rescue operations, and perhaps even for a taxi service to the Moon and Mars.

CHAPTER 10

NAVAL SPACE FACILITIES

THE
NAVY'S
ROLE
IN SPACE

The chapters that follow will be devoted primarily to space applications that depict some of the Navy interests in space. Without attempting to delineate what applications are unique to Naval operations and which may be applicable to other services as well, we shall consider the applications of Earth satellites in a military environment under five functional areas:

First, we have data gathering in space. The Navy was a pioneer in this area with early and continuing work in probes, satellites, and other experiments such as SOLRAD now being conducted in space. Chapter Twelve will cover this area in detail.

The second functional use of satellites is as a communications antenna. Just as communications have been improved by operating antennas at mast head heights, the Earth satellite, operating at hundreds or thousands of miles altitude provides extended line-of-sight ranges thereby overcoming some present-day limitations. For example, an Earth satellite provides the possibility for extended use of VHF or higher frequencies that are normally limited to much shorter ranges. More details will be furnished on this valuable application in Chapter Thirteen.

A third area is using a satellite as an observation platform. The advantages of placing various sensors at extreme altitudes to observe the Earth is primarily that of the tremendous area coverage obtained by fast-moving satellites. They move at about five miles per second and with average view angles sweep out thousands and thousands of square miles of surface each minute. In addition, the ability to view the total Earth as an entity, such as in the measurement of overall gravitational and electromagnetic fields, is of special significance. Chapter Fourteen discusses observations from space.

As our fourth area, an Earth satellite can serve as a unique reference point for geographic measurements. Such uses of satellites as a navigation reference, as an intercontinental time reference, and as a tool for use in geodesy and mapping fit into this category. Chapter Fifteen describes Geodetic and Navigational satellite Systems.

The fifth function area, of potential concern, is the area of space defense. The national need for a device to intercept, observe, and possibly neutralize another hostile satellite is a major military concern. This would be particularly true if unfriendly nations develop and employ satellite technology to hamper our national objectives or interfere with Naval operations. Chapter Sixteen will explore some aspects of this military application of space.

NATIONAL
U.S. NAVY

After thorough consideration of the technical aspects of space, the economic impact of space programs, and current work underway by other agencies (Air Force, Army, NASA, ect.), the Navy's policy is to concentrate its efforts on the practical exploitation of space technology for Naval purposes in each of the five functional areas just described.

The Navy's emphasis is placed today on developing an understanding of space technology; devising simple, straightforward applications that will give immediate pay-offs, and placing these new tools in the hands of its well-qualified Naval personnel. The Navy is maintaining a realistic cost-conscious approach to space systems, standing alert and ready to augment or replace conventional systems whenever the change will benefit the Navy and the Nation.

To carry this policy into effect the Navy possesses a flexible organization for space centered formost in the offices of the Chief of Naval Operations, Chief of Naval Material, and the various Systems Commands. Of primary importance to Navy space programs is the project coordination furnished by CNO (Op-76), Air Systems Command (AIR-538), and the newly commissioned Navy Space Systems Activity at El Segundo, California. The creation of the Navy Space Systems Activity (NSSA) in late 1966 is indicative of the Navy's desire to cooperate fully in the multiservice approach to space. NSSA is located with the Space and Missile Systems organization (SAMSO) of the Air Force which is the primary agent for the Air Force in space applications. One of the missions given to NSSA is to be responsive through the Naval Air Systems Command to requirements of other Naval activities who are responsible or participating in the development of systems which interact with space systems. Since there are numerous such Naval activities interacting, NSSA represents a step forward in project coordination among Naval facilities in the Space Age. Let us now meet some of those participants that are changing concepts into hareware so that space systems will benefit the Fleet today and in the future.

NAVAL SPACE FACILITIES

Throughout the years the Navy has developed technical competence and practical experience in the fields of meteorology, rocket propulsion, cosmology, human engineering, electronics, medicine, and a host of other areas which have contributed to our Nation's accomplishments in space. The Navy's participation in these and other scientific endeavors has grown in direct proportion with the Navy's development of laboratory facilities which are partially listed in Table I at the end of this Chapter. (Names of Navy commands in this chapter are in historical context recognizing that some have subsequently undergone change.)

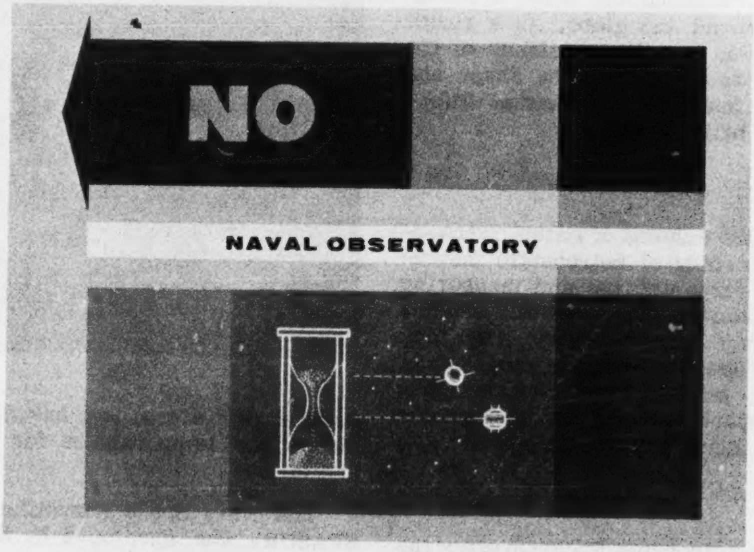
Collectively, these facilities and the similar laboratories of the other military services, together with the Nation's space industry and the National Aeronautics and Space Administration, constitute what might be call the National Space Team. Leader of this National space effort is the National Aeronautics and Space Administration (NASA). However, attention will now be directed to a more detailed discussion of some of the programs, efforts, and capabilities of a number of the Navy's space facilities, for the purpose of showing typical involvements of Navy facilities in the national space program.

Naval Observatory
(Washington, D. C.)

The mission of the Naval Observatory (NO) is to make observations of celestial bodies, to derive and publish such data as will afford means for safe navigation, and while pursuing this primary function, to contribute material to the general advancement of navigation and astronomy. Fulfillment of this basic mission includes observation of both natural and artificial celestial bodies, derivation and publication of accurate time signals, and the development of data necessary for space navigation.

The Naval Observatory, established in 1830, has a longer history of space studies than any other scientific institution in the Navy. It is often considered to be our "National Observatory" and is the source of all standard time used in this country, as well as within the Department of Defense. The Naval Observatory is assigned responsibility as the Single Service Manager for establishing, coordinating and maintaining accurate time and time intervals for the Department of Defense.

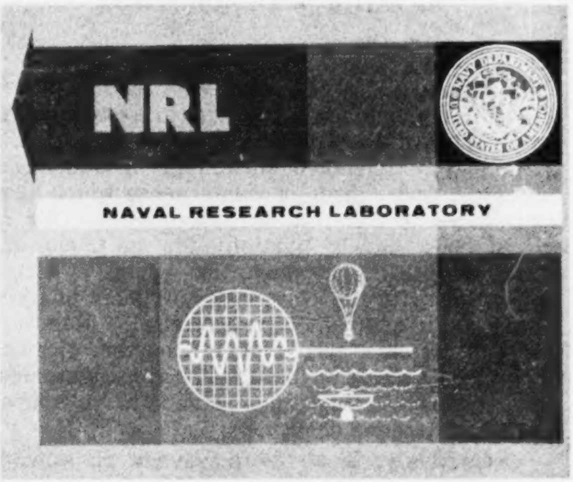
The Naval Observatory is the source of special planetary and satellite ephemerides as well as other published astronomical data pertinent to navigation like the Air and Nautical Almanacs.



Naval Research Laboratory
(Washington, D. C.)

Under the direction of the Chief of Naval Research, the mission of the Naval Research Laboratory (NRL) is to conduct scientific research and development in the physical sciences directed toward new and improved materials, equipment, techniques, and systems for the Navy.

In space related projects NRL personnel have conducted an upper-air research program, pioneered and conducted experiments in Earth Satellite Programs, created the Navy Space Surveillance System for detecting non-radiating satellites, and worked in the field of radio astronomy. The scope of the NRL research program includes astronomy, astrophysics, basic physics, optics, sound and a number of other disciplines. NRL stands today as one of the foremost physical research laboratories in the world. NRL has been active in major space-age programs for over a decade, some of which are discussed in the following paragraphs.



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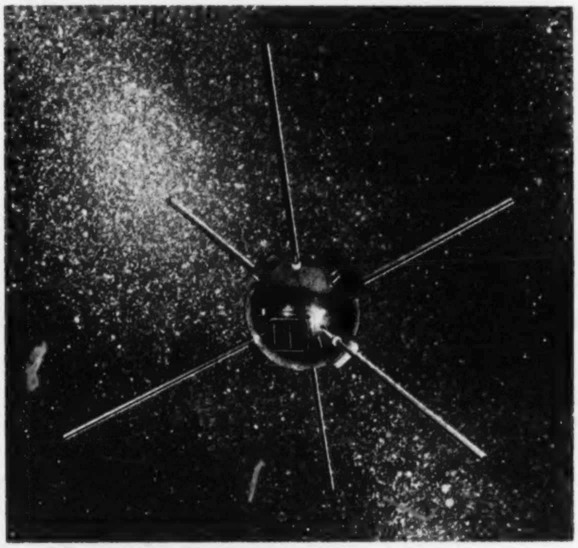
Satellite Research

NRL scientists launched the VANGUARD test vehicle and placed the VANGUARD Satellite into orbit on 17 March 1958. An estimate of its lifetime in orbit has been calculated to be approximately 2000 years. This satellite was used by NASA to calibrate the NASA tracking stations located around the globe. As a result of this and follow-on satellites, islands of the Pacific have been relocated and the shape and crust of the Earth found to be somewhat different than previously believed.

Rocket Astronomy

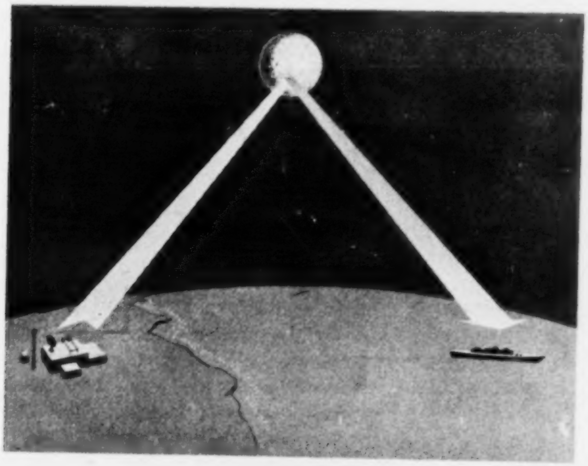
NRL pioneered the science of rocket astronomy, which is the loading of astronautic instruments in a rocket for gathering and measuring near-space data. Two highlights in this science of rocket astronomy occurred when NRL took the first detailed spectrographic photograph of the Sun in 1959, showing the Lyman Alpha emission line of hydrogen, and the first photograph of X-rays from the Sun in April 1960.



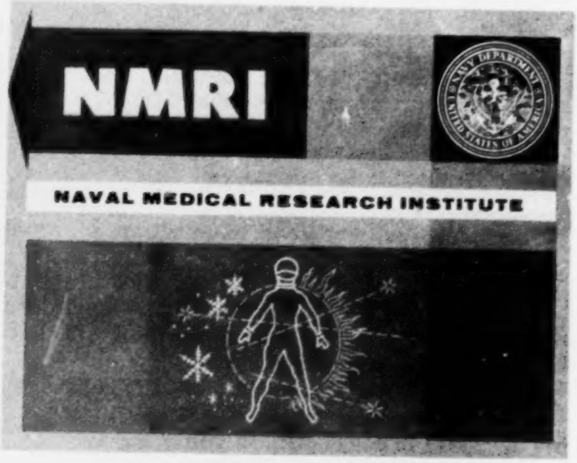
Radio Astronomy

The NRL Radio Astronomy Program concerns itself with radio frequency emissions from the Sun, planets and the stars. NRL has discovered several new stars, and has determined a range of surface temperatures for Venus, Mars, and Jupiter.

The Navy Space Surveillance System (NAVSPASUR) was developed by the NRL to detect, track and predict the orbits of all satellites passing over the United States.



In 1951, NRL investigated the potentialities of a radio circuit via Moon reflection. In 1962, NRL sent messages by way of the Moon to a moving ship; in this case, the signal was transmitted from the 60-foot antenna located at Stump Neck, Maryland, and received by the research ship U.S.S. OXFORD operating in the Atlantic.



Naval Medical Research Institute
(Bethesda, Md.)

The Naval Medical Research Institute (NMRI) is another of the Navy field activities that is engaged in the overall space effort. With its highly specialized staff, the Institute has capabilities in many scientific fields.

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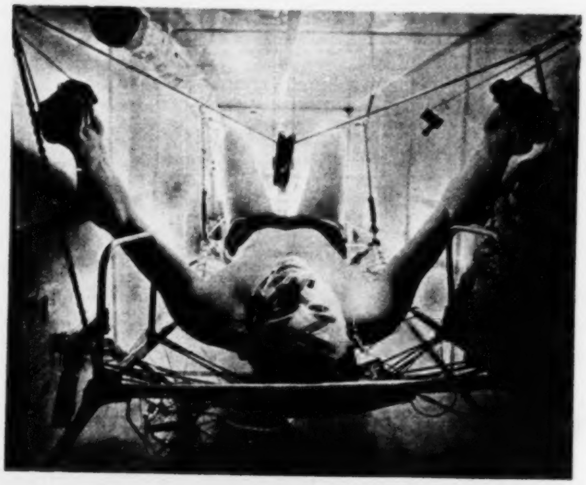
NMRI is conducting programs relating to the physiological effects on man in both normal and extreme environments. Considerable effort is directed towards human calorimetry research and vibration-accelerations. In support of vibration research the Institute's research with a high-speed X-ray machine, capable of taking up to 400-frames per second, has proven quite useful in the analysis of human vibration, impact, and shock. These experiments may determine how much vibration man can endure in spacecraft during re-entry.

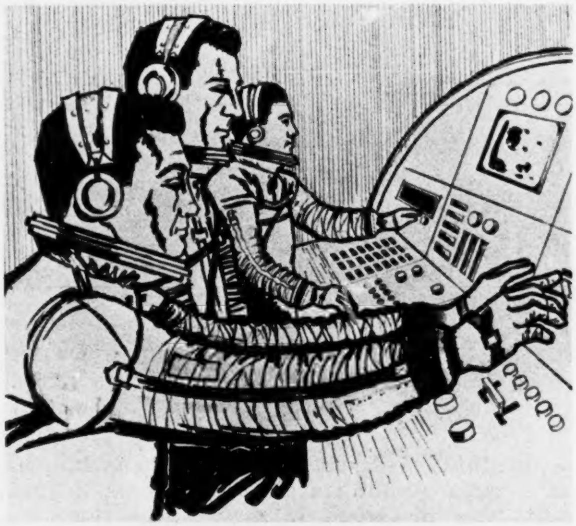
Through experience with personnel in isolated locations such as POLARIS submarines, radar picket ships, and on Operation Deep Freeze, it has been determined that future operational systems may have strange psychological effects on crews and their ability to perform required tasks. It became clear that crew selection procedures for ocean bottom exploration (perhaps analogous lengthy space travel) must be broadened to evaluate personnel in terms of the specific group with which they will serve. Thus, heavy psychiatric preconditioning will be given crew members who must perform effectively under conditions of prolonged physical and geographical isolation, and in environments severely restricted as to amount and variety of sensory stimulation.



As a result of this potential problem, a research effort termed Program ARGUS is studying the social and emotional effects of space-like situations which man has not yet had to face. These include a combination of:

1. Intensive, enforced interaction of small groups.
2. Sustained demands for vigilance in reaching rapid and irreversible decisions.
3. Prolonged total isolation in a sensory-poor environment.
4. Total interdependence of all individuals for group survival.
5. Total impossibility of removing an ineffective crew member.

Although the initial purpose of Project ARGUS was to anticipate problems of crew effectiveness in future Naval environments, the results of this study can provide insight into space crew selection.



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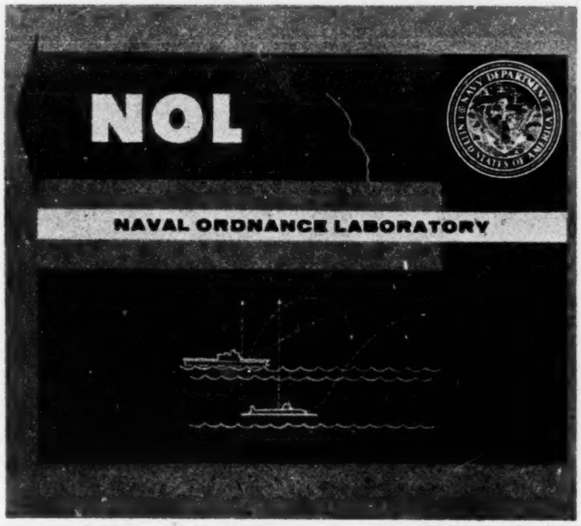
Naval Ordnance Laboratory
(White Oak, Maryland)



The Naval Ordnance Laboratory (NOL) has as its stated mission to conduct research, design development, test and technical evaluation of complete ordnance systems, assemblies, components, and materials pertaining to existing, advanced and proposed weapons, principally in the fields of missiles and underwater ordnance. As a result of involvement in many space-age programs, NOL has accomplished numerous ordnance feats. A partial list would include the arming and fusing mechanism for the POLARIS missile, furnishing design data for the TERRIER, TARTAR, TALOS, SIDE WINDER, PERSHING, ATLAS and TITAN missiles, and the development of explosives used in the Gemini satellites.

The Naval Ordnance Laboratory has also placed emphasis on studying missile re-entry wakes in an extensive testing program. The aerodynamic characteristics of wakes are investigated through the use of shadowgraphs and photographs of the airflow behind re-entry models in flight.

NWL
NAVAL WEAPONS LABORATORY

Naval Weapons Laboratory
(Dahlgren, Virginia)

The Naval Weapons Laboratory (NWL) is well known for its activity in the fields of weapon development and evaluation, warhead and terminal ballistics design, explosives and propellant research. NWL also has significant projects in space-related areas. The Naval Space Surveillance System, a radar watchdog of space, was established as an operational facility at the NWL in 1960.

The Laboratory's work in the area of satellite geodesy is also of significance. NWL is responsible for the determination of the shifts of major datums and isolated sites with respect to the center of mass of the Earth, as well as the determination of the value of the mathematical series expansion for the gravitational field of Earth.

Other projects at NWL include research in celestial mechanics which resulted in discovery of the motions of the Planets PLUTO and NEPTUNE. Smaller scale projects at the Laboratory relate to analysis of telemetry data satellite-borne sensors such as photocells, and computer analysis of the angular motion of satellites subject to gravitational and magnetic torques.

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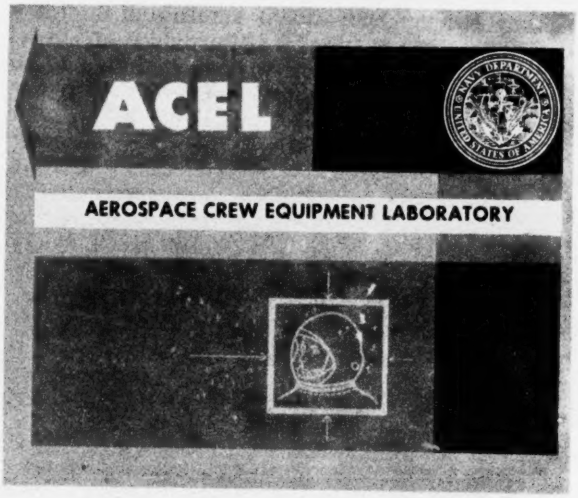
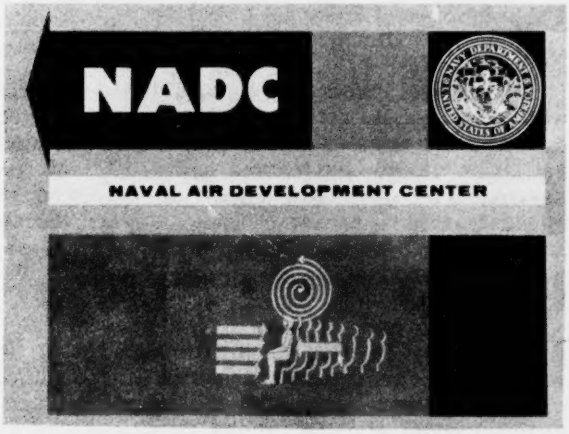
Aerospace Crew Equipment Laboratory
(Philadelphia, Pa.)

The Aerospace Crew Equipment Laboratory (ACEL) of the Naval Air Engineering Center, has conducted programs relating to the engineering, physiological-psychological, and training aspects of manned space-flights. The Laboratory's work with high-altitude, full-pressure suit investigations has been fruitful. The results led to the development of the operational MK-IV full-pressure system used by Project MERCURY Astronauts and naval aviators.

The Bio-Astronautical Test Facility of ACEL is investigating the ability of men to live in a full-pressure suit for extended periods of time at various pressures. The results of this research were extremely helpful in the planning and excecution of the GEMINI space missions, and continuing efforts will support the APOLLO Programs.

The high-altitude training chamber can simulate altitudes up to 260,000 feet. It has a temperature range from a minus 150° F to a plus 750° F. This chamber can test the APOLLO space module completely enclosed.





Naval Air Development Center

(Johnsville, Pa.)

The Naval Air Development Center (NADC) is another Naval facility which has been a foremost contributor to space research. One excellent example of the space-oriented activity performed at the Center pertains to the centrifuge that is used to conduct tests to learn the effects of space-flight on the human body. Simulated flights for X-15 pilots have been conducted at this facility, and astronauts have received simulated mission training for MERCURY and GEMINI.

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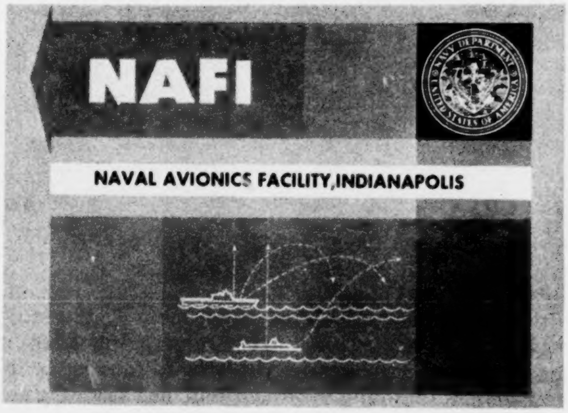
Naval Avionics Facility

(Indianapolis, Indiana)

The Naval Avionics Facility (NAFI) is perhaps best known for its work in the development, design, and limited manufacture of equipment associated with Naval weaponry.

Under one roof, NAFI offers 11¼ acres of shop space mainly devoted to quick-response manufacturing proposals. NAFI is currently engaged in about 600 different projects ranging from repair of missile guidance systems to the manufacture of prototype satellite parts. NAFI was originally designated by the Navy as the production agency for the operational satellite of the Navigation Satellite System. NAFI provides all necessary services to assure proper injection of the satellite into a satisfactory orbit.



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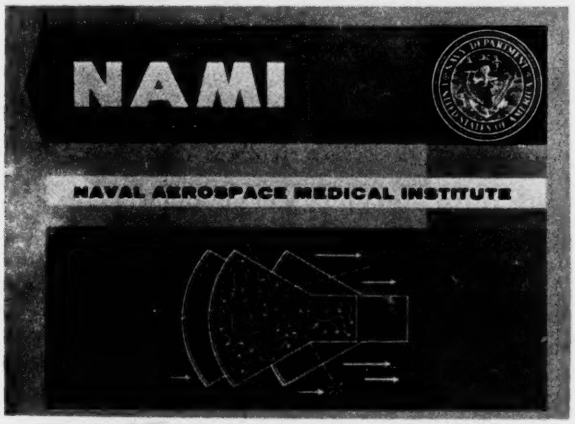

Naval Aerospace Medical Institute

(Pensacola, Fla.)

The mission of the Naval Aerospace Medical Institute (NAMI) includes conducting a broad program of basic and applied research in the fields of aviation and aerospace medicine, especially in the areas of cosmic radiation, exotic environments, magnetism, disorientation, weightlessness, and the establishment of guide lines for the selection and training of astronauts.

The Institute brought attention to the Navy's early space role in May, 1959, when it sent the first primate, Miss Baker, (a squirrel monkey from the jungles of South America) on her historic trip in the nosecone of an AEROBEE Rocket. Her flight aboard a missile into space gave research scientists at the Center early information for the development of techniques for capsule recovery and the monitoring of medical data from living animals in space.

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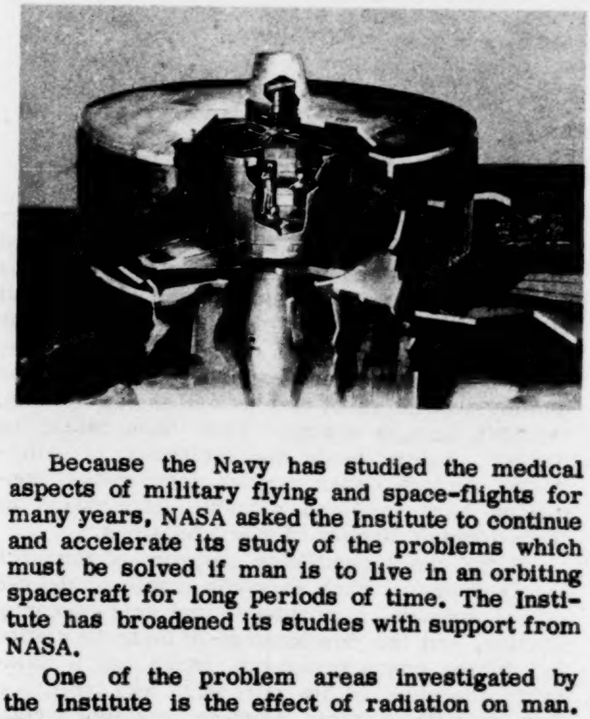


Because the Navy has studied the medical aspects of military flying and space-flights for many years, NASA asked the Institute to continue and accelerate its study of the problems which must be solved if man is to live in an orbiting spacecraft for long periods of time. The Institute has broadened its studies with support from NASA.

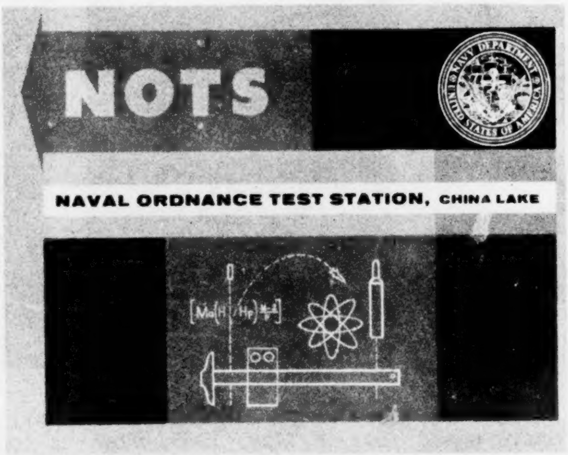
One of the problem areas investigated by the Institute is the effect of radiation on man. Since man-on-earth is protected partially from radiation by the Earth's magnetic field, the Institute is studying the possibility that magnetism can be used in a protective fashion about a spacecraft. In fact, all experiments in space are reviewed by the Aerospace Medical Institute to assist in their evaluations of the extent, of the radiation problem. The Institute, which is one of the finest vestibular research centers in the world, is also studying the effects of various motions encountered in space that will affect man's inner ear. To counteract weightlessness, future space stations may be built so that they spin slowly and create an effect similar to that of the Earth's gravity. To learn more about the possibilities of such an approach to a space problem, a Coriolis Acceleration Platform was constructed at the Institute. This mechanism enables the effects of linear motion to be studied in combination with various angular motions. It permits the accurate simultation of many of the bizarre combinations of force stimuli which may occur in flight operations and the study of their effects on crewmen under carefully controlled conditions.

Also included in the many areas of research performed at the Institute is the activity centered around studies of the effects of zero gravity. For instance, acceleration of the body caused by the minute driving force of the heartbeat has been measured accurately.

Naval Ordnance Test Station
(China Lake, Calif.)

The Naval Ordnance Test Station (NOTS), in addition to its competent ordnance activities, has capabilities to conduct space research in a number of areas. The station has a well-integrated team of over 6000 graduate civilian and military scientists, engineers, and technical support personnel. NOTS possesses the capability of following a project from basic research through feasibility demonstration, pilot production, test and evaluation, and subsequent release to the fleet. The Michelson Laboratory is the hub of Astronautics' effort at NOTS, and is one of the world's most complete research and development centers.

Other NOTS capabilities which support astronautics programs include the highly instrumented SKYTOP I (a solid-rocket facility capable of providing static-test firing of POLARIS motors in the horizontal position; SKYTOP II for static-test firing in either the vertical or horizonal position; SKYTOP III for handling motors known or suspected of being defective. The SKYTOP data-acquisition system is capable of gathering 200 channels of information and can be switched quickly from one test bay to another.



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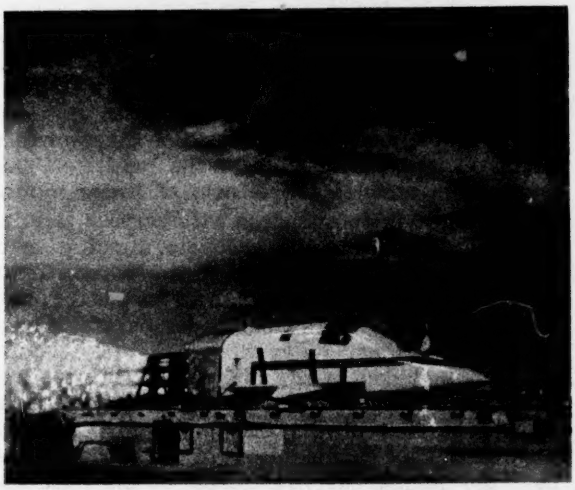
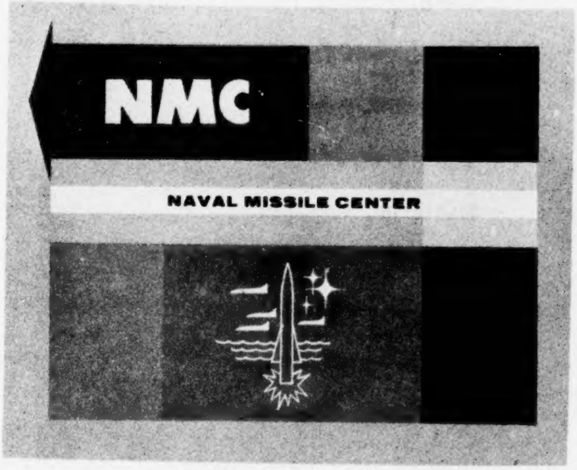


SNORT, (the Supersonic Naval Ordnance Research Track, which is 4.1 miles long) is used for testing astronautic components, such as inertial platforms, while under acceleration and vibration. Components can be tested on this track under controlled conditions which may include human factors experiments. These use dummy-type or robot men as well as live animals. GEMINI escape systems have been tested on SNORT. Large scale destruct-tests of solid-rocket motors under various acceleration conditions have provided valuable information on the explosive dangers of space boosters.

NOTS has a continuing program of research in other areas, such as study involving the use of sea animals, atmospheric and environmental studies, and the development of instrumentation for future space programs. NOTS has a flexibility (because of its personnel and facilities) that permits a rapid shift to any appropriate space project.

Naval Missile Center
(Point Mugu, California)



The Naval Missile Center (NAVMISCEN), in over twenty years of operation, has developed unique test and evaluation capabilities. These include a wide variety of laboratory facilities, the availability of aircraft and targets, and the facilities of the highly instrumented Sea Test Range.

Astronautic research programs conducted by the NAVMISCEN have provided various contributions to the mobile launch concept for sending payloads into space. This has been accomplished through the utilization of both aircraft and sea launch techniques. Other work has been conducted in the fields of the Navigational Satellite System, tactical probes, and Ocean Surveillance. The Space and Astronautics Orientation Course for senior personnel of the Navy Department is based at the Naval Missile Center.

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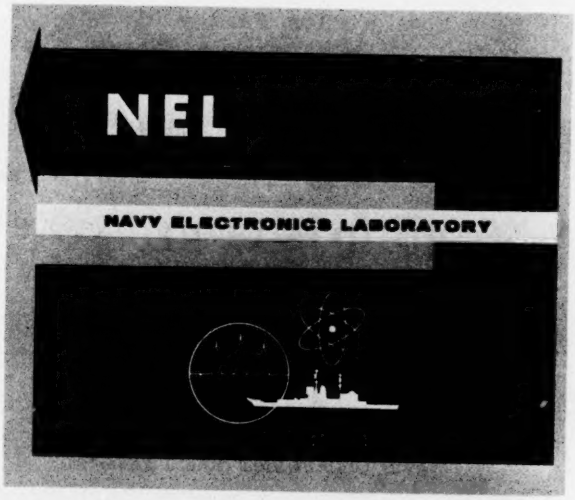
Naval Electronics Laboratory
(San Diego, Calif.)

The final Navy facility to be discussed is the Naval Electronics Laboratory NEL). This Laboratory presently is supporting the Navy Space program in three major areas:

(1) Defense Communication Satellite Program (DCSP), to provide communications for a variety of users including aircraft, ships, submarines, and field troops.

(2) The tactical Satellite Communication Program (TACSATCOM).

(3) The Shipboard Meterological Satellite Readout Station to be used in conjunction with selected ships of the fleet.



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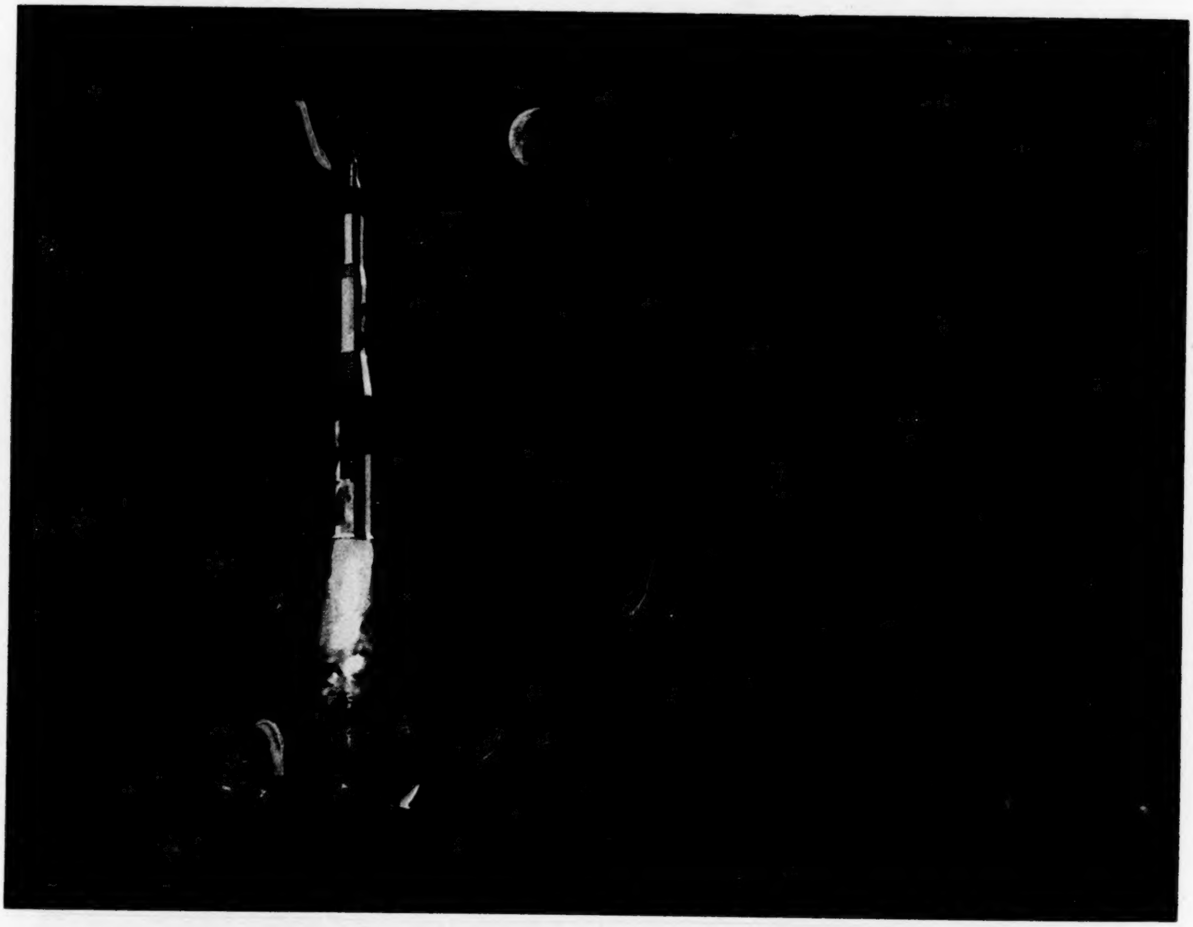
This brief view of the capabilities and achievements of a few of the Navy's field activities certainly permits a realistic conclusion that the space achievements of our Nation owe a great deal to Naval research and development. Although the Navy Laboratories were not necessarily designed for the space age, when the challenge of the space race appeared, they responded in a most commendable fashion to lend their talents where appropriate.

TABLE I

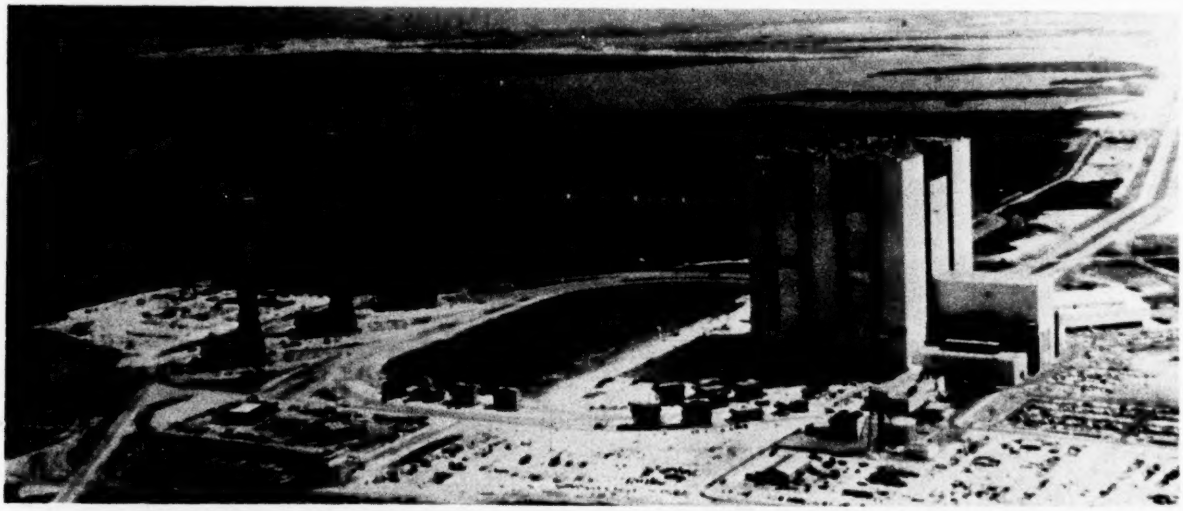
FACILITY	LOCATION
Naval Observatory	Washington, D. C.
Naval Research Laboratory	Washington, D. C.
Naval Medical Research Institute	Bethesda, Maryland
Naval Ordnance Laboratory	White Oak, Maryland
Naval Weapons Laboratory	Dahlgren, Virginia
Naval Air Engineering Center	Philadelphia, Pennsylvania
Naval Air Development Center	Johnsville, Pennsylvania
Naval Avionics Facility	Indianapolis, Indiana
Naval Aerospace Medical Institute	Pensacola, Florida
Naval Ordnance Test Station	China Lake, California
Naval Missile Center	Point Mugu, California
Navy Electronics Laboratory	San Diego, California
Naval Air Test Facility	Lakehurst, New Jersey
Naval Air Turbine Test Station	Trenton, New Jersey
Naval Underwater Weapons Station	Newport, Rhode Island
Naval Medical Field Research Laboratory	Camp Lejeune, North Carolina
Naval Training Service Center	Orlando, Florida
Applied Physics Laboratory, John Hopkins University	Silver Spring, Maryland
David Taylor Model Basin	Carderock, Maryland
Naval Applied Science Laboratory	Brooklyn, New York
Naval Underwater Sound Laboratory	New London, Connecticut
Naval Propellant Plant	Indian Head, Maryland
Naval Ordnance Missile Test Facility	White Sands, New Mexico
Naval Ordnance Laboratory	Corona, California
Naval Biological Laboratory	Oakland, California
Naval Radiological Defense Laboratory	San Francisco, California

CHAPTER 11

LAUNCH TECHNIQUES



Before entering into a more detailed discussion of programs, it is appropriate to consider the various launch techniques by which probes and satellites are sent into space. Launch platforms merely support missiles or space boosters until they are fired and these supports come in various forms. Platforms can be fixed or mobile; above or below ground level; shipborne on the surface or below the surface of the ocean; and airborne. Launchers can fire vertically or near-horizontally from simple concrete pads, silos, tubes, rails, aircraft, or from water itself.



LAND LAUNCH

The simplest zero-length launchers for the smaller solid-propellant rockets differ greatly from the extensive launch complexes for the largest liquid-fueled space boosters. The largest solid-fueled and liquid-fueled space boosters are customarily launched from the national ranges. Manned spacecraft and deep space probes are launched from the Eastern Test Range (ETR) from launch complexes as large as the SATURN installation, which will be used extensively for the larger space probes of the future. Both military operational missiles and satellites are launched from the Western Test Range (WTR) using concrete launch pads on the ground or concrete silos below ground level.

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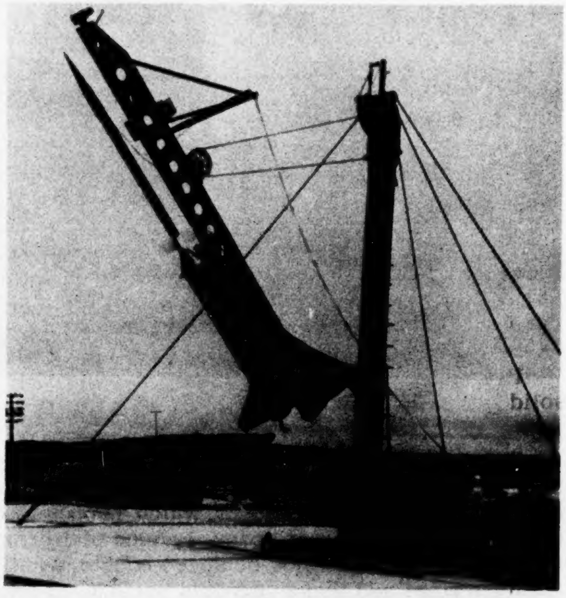
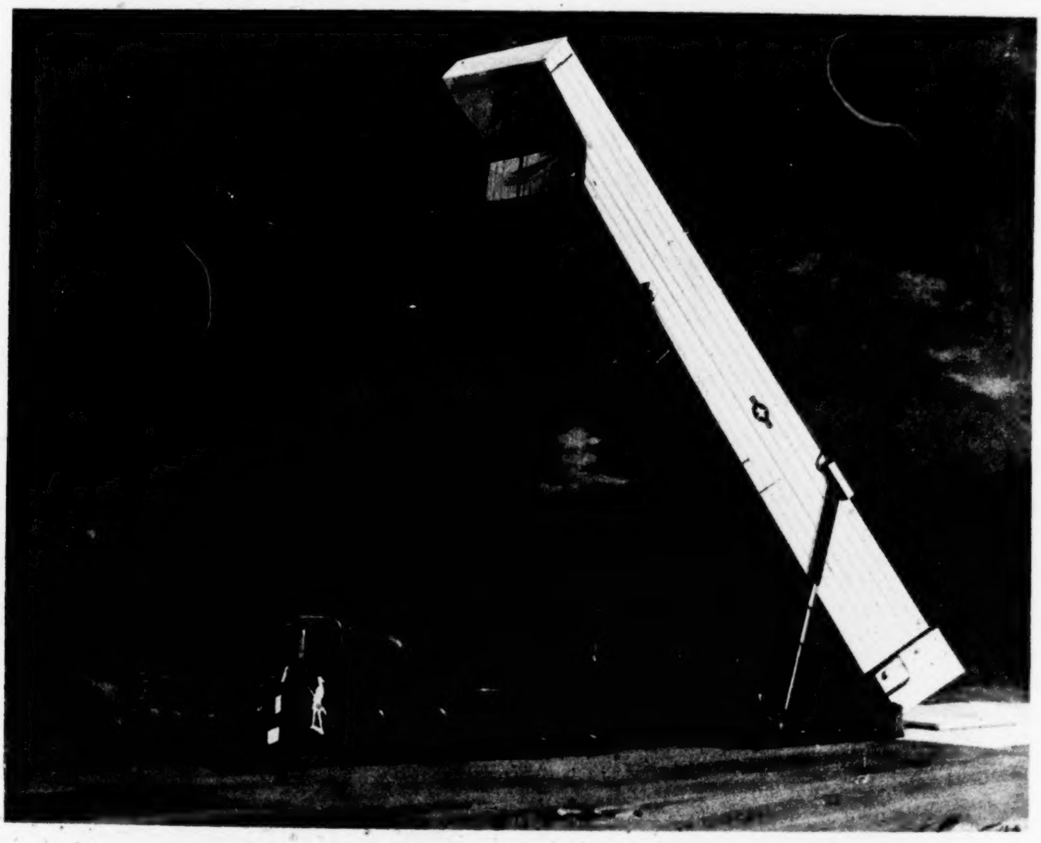
The support facilities required for erecting, preparing for launch, and launching ground-based rocket-propelled vehicles vary. For small, vertically launched rockets, the launching facility may consist of a steel ring on a concrete pad. For non-vertically launched missiles, a zero-length or rail-type launcher may be used. (A concrete blockhouse or bunker is often used to protect personnel during the launch sequence.)



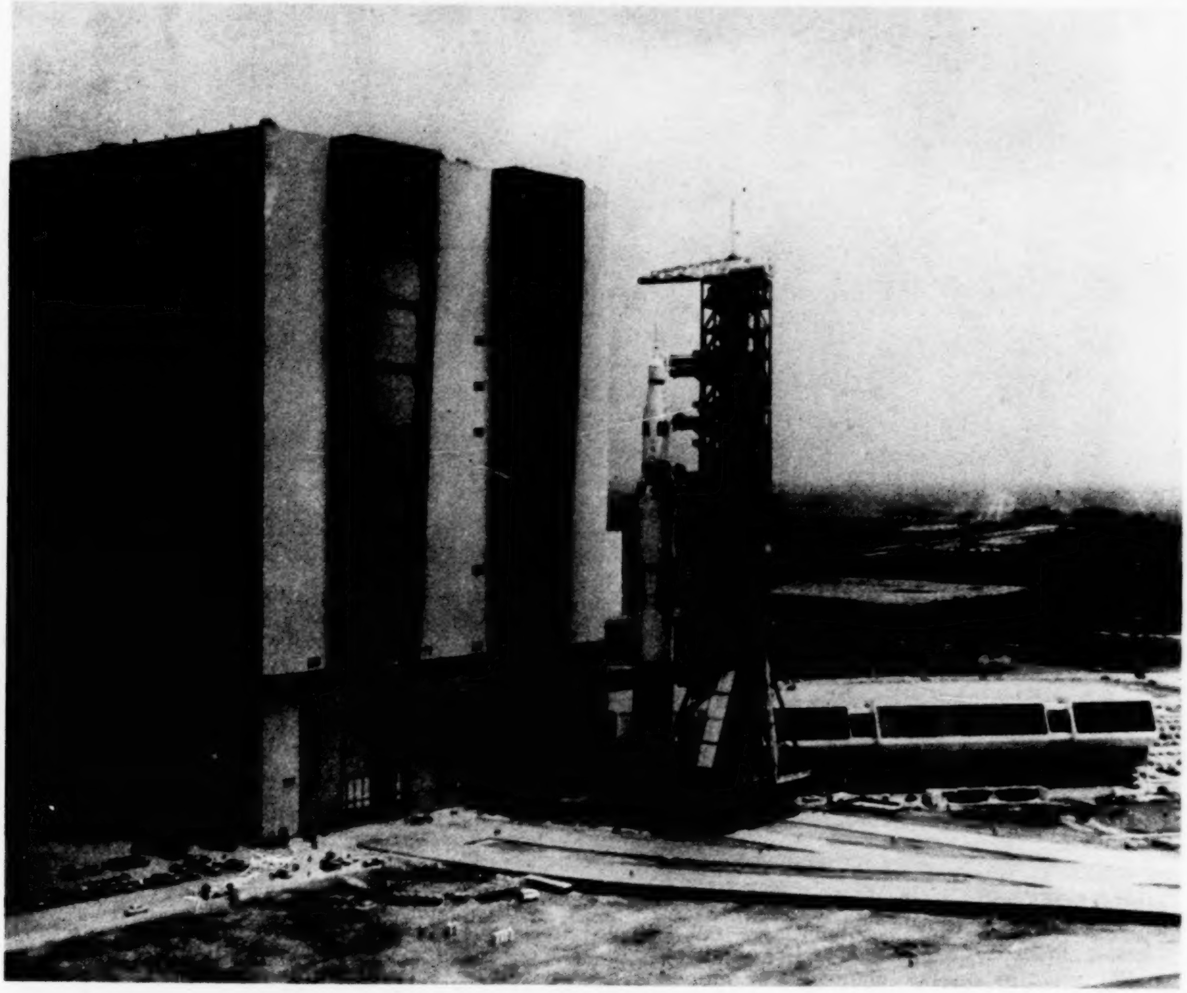


For large solid-propellant rockets, the launch complex consists of a dry launch pad, a launch stand, service tower or gantry to permit access to the missile during checkout, a blockhouse for personnel during launch, and the usual ground support equipment. The weighing of the solid-propellant motors, and the static tests are normally done before transport to the launching sites. Any launch-stand checkout must be conducted with the missile in a hazardous condition. For safety and fire prevention, major subsystems are usually checked out separately in an isolated assembly area.

The cylindrical concrete launch silo for the solid-propellant MINUTEMAN II is 94 feet deep and 12 feet in diameter. The overall length of the three-stage, solid-fueled ICBM is 56 feet and the diameter is only 5 1/2 feet. An unmanned two-level equipment room contains the electronic equipment and cabling required to monitor the missile and initiate launch on command from the launch center. A remote launch control support building contains crew living quarters, environmental control equipment, and power and communications equipment for personnel in the launch control center.

During movement from the assembly plant to the launcher, a transporter-erector provides a controlled environment for the missile and erects the missile for emplacement in the launch tube. A reinforced concrete door which protects the silo is moved horizontally from the path of the missile very rapidly prior to launch. The MINUTEMAN II is launched out of the silo so rapidly that the exhaust gases are not ducted to the atmosphere separately from the launch silo. After launch from its underground silo, the missile rises vertically for several seconds, and then pitches over gradually. Yaw and roll alignments are accomplished during second and third stage burn. The re-entry vehicle or warhead separates after third stage thrust is terminated and continues to the target at speeds exceeding 16,000 mph.

134

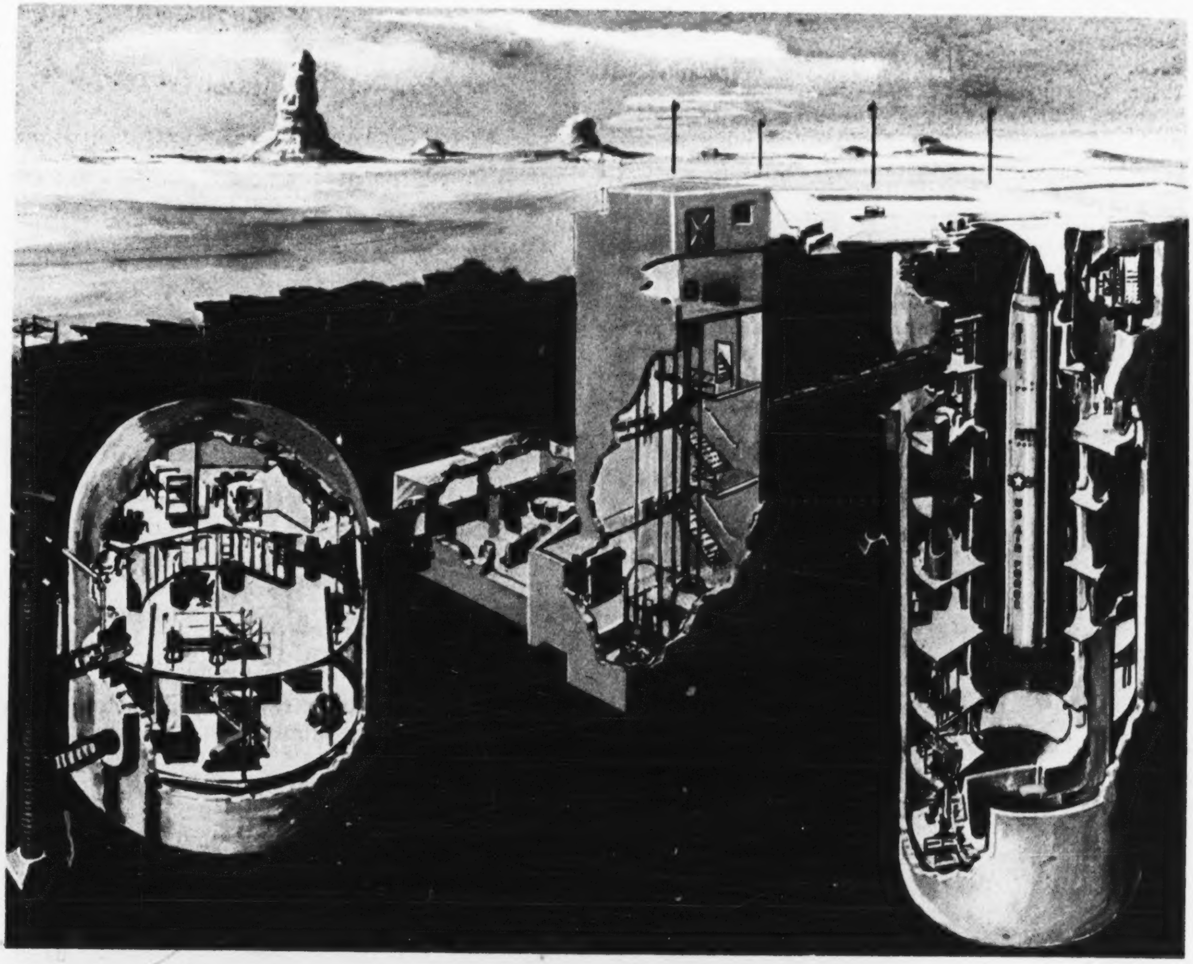


The world's first successful land launch of a liquid-propellant rocket was achieved by Dr. Goddard from a Massachusetts farm in 1926. Development of liquid-fueled rockets has progressed rapidly. Its crowning achievement to date is the gigantic SATURN V. The first stage of SATURN V is 33 feet in diameter (excluding fins) and consists of five engines (each developing 1,500,000 pounds of thrust, totaling 7.5 million pounds of thrust). At launch, with the APOLLO spacecraft on top of its third stage, the SATURN V towers 365 feet high over Cape Kennedy.

For large liquid-propellant missiles like the SATURN, the launch complex is extensive. In addition to the usual hardstand, the mobile launcher, the launch utility tower, launch control center and ground support equipment, liquids require elaborate fuel storage, loading and weighing facilities and usually a water-cooled flame deflector for diverting the engine exhaust, and a hold-down and release system. Strain gauges which measure structural deformation by electrical properties are usually used in the weighing systems. The blockhouse contains test and control consoles and recording equipment to check and launch the missile remotely. Data from the launch is recorded automatically. Before launch, readiness of down-range equipment, weather, instrumentation equipment, and the final checkout during the countdown must be assured.

A spacecraft received at the launch pad must be thoroughly tested before being mated to the launch vehicle for final checkout. The primary link between the spacecraft and the rest of the ground support complex, including the tracking and communications networks, is through the umbilical cable that feeds power, gas, hydraulics, and electrical signals. Before the umbilical is broken at launch, final calibration of onboard instrumentation and final verification of system operational readiness must be assured. Final launch checkout may vary from a few minutes for military operational missiles such as TITAN II using automatic checkout equipment, to several weeks for complicated experimental type launches.

The reinforced concrete silo used for launching TITAN II missiles is 155 feet deep and 55 feet in diameter. The missile silo houses the 103-foot tall, two-stage, liquid-fueled ICBM and support equipment. Crew members work and live in the control center. The separate structures are connected by tunnels and the entire complex is "hardened" or designed to withstand enemy attack. During the readiness state, the missile and critical equipment are mounted on shock isolation systems to avoid damage from nuclear blasts. Each missile complex has wind and temperature-gradient sensing devices to warn of hazard areas containing toxic gases released by burned propellants. The silo is protected by a 750-ton silo door which is moved horizontally out of the missiles launch path in a matter of seconds. The missile is fired without being raised to above ground level.



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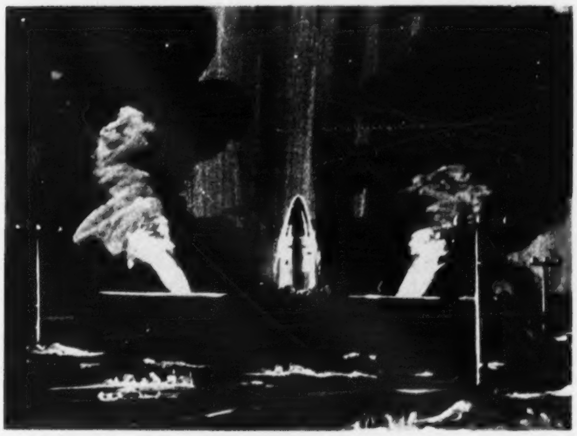

The TITAN II missile is launched out of the launch tube, with the exhaust gases conducted above ground to the atmosphere by separate ducts. After launch from its underground silo, the missile rises vertically for several seconds, properly aligning itself with the target. Then the missile pitches in a curving trajectory during first stage thrust, reaching supersonic speed. When the first stage is shutdown, the second stage ignites and separates, reaching speeds of 15,000 miles per hour. The last step in the sequence is when the re-entry vehicle or warhead sparates and continues to the target.

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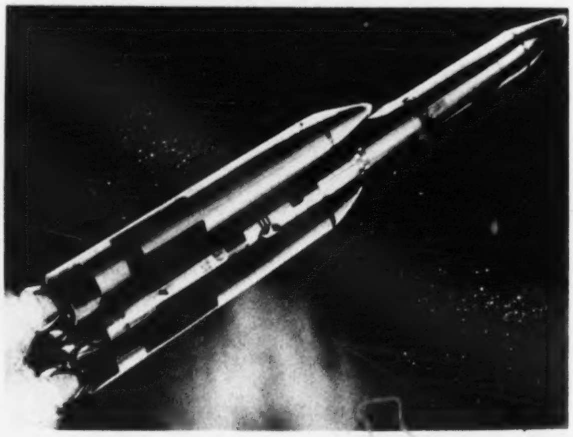
The land launching of solid-propellant and liquid-fueled rockets has progressed to the 10-foot diameter solid-propellant boosters strapped onto the 10-foot diameter core of the TITAN IIIC. Each solid-rocket motor is 85 feet long, weighs 250 tons, and generates over 1,000,000 pounds of thrust. The TITAN IIIC liquid-fueled core with the two solid-propellant boosters is presently launched from the Eastern Test Range (ETR) launch pads, collectively known as the Integrated Transfer Launch (ITL) complex. Ejection rockets, mounted on the forward and aft ends of each solid-rocket motor, thrust the expended motor casings away from the core vehicle after launch .



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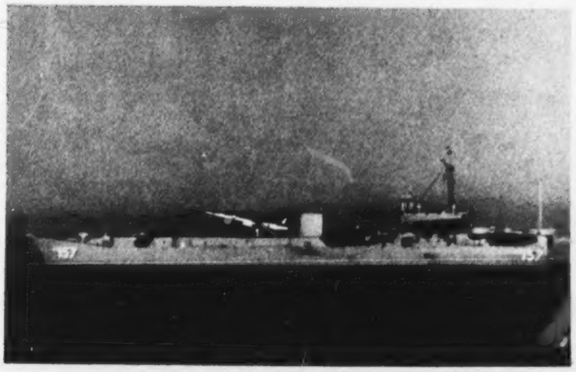
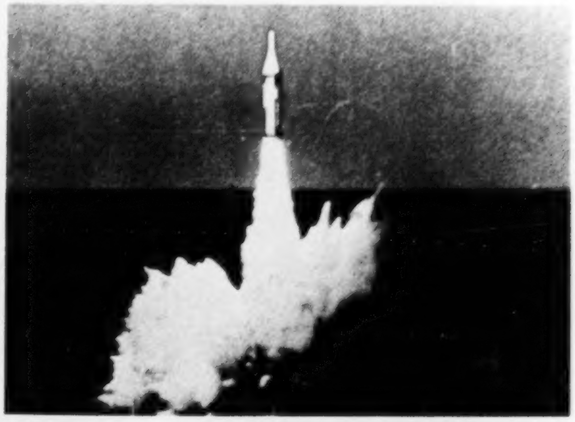


WATER LAUNCH

Before 1960, the first operational missiles to be launched from submarines were the winged, medium-range REGULUS missiles. The subsonic REGULUS vehicles were boosted by solid-jet-assisted-take-off rockets and sustained in flight by turbojet engines. The missiles were enclosed in cans on top of the submarines and launched on the surface from zero-length launchers.

137

The next natural step was to develop a technique for launching from beneath the surface. This was achieved in 1960 by the firing of the A-1 fleet ballistic missile (POLARIS) from the GEORGE WASHINGTON. POLARIS is a two-stage solid-propellant missile. The A-3 missile is 31 feet long, and four and one-half feet in diameter with a range of about 2800 miles. The A-2 was slightly smaller in dimensions with a range of 2000 miles. Each missile weighs about 15 tons. It carries a powerful nuclear warhead. They are launched by an air or steam ejection system which forces the missile from its launching tube, through the water, and to the surface. Each launching tube has its own air or steam supply, independent of the other 15 tubes. Vital parts of each missile are accessible for inspection and maintenance even when loaded in the launching tubes and while the submarine is submerged at sea. Only upon reaching the surface after launch does the rocket motor ignite and send the missile on its way.



The is possible because of the reliability and instantaneous ignition characteristics of the solid-propellant. Ths safety advantages to the submarine and its crew are obvious.

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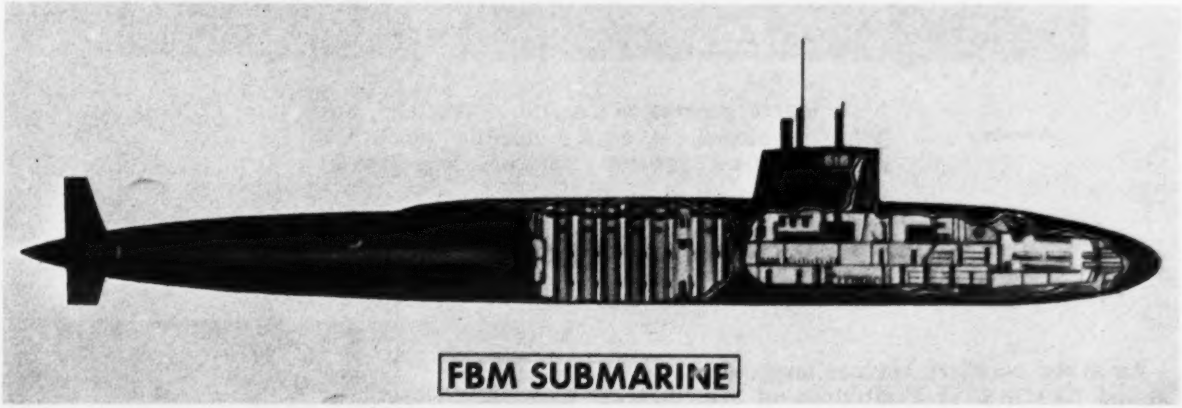
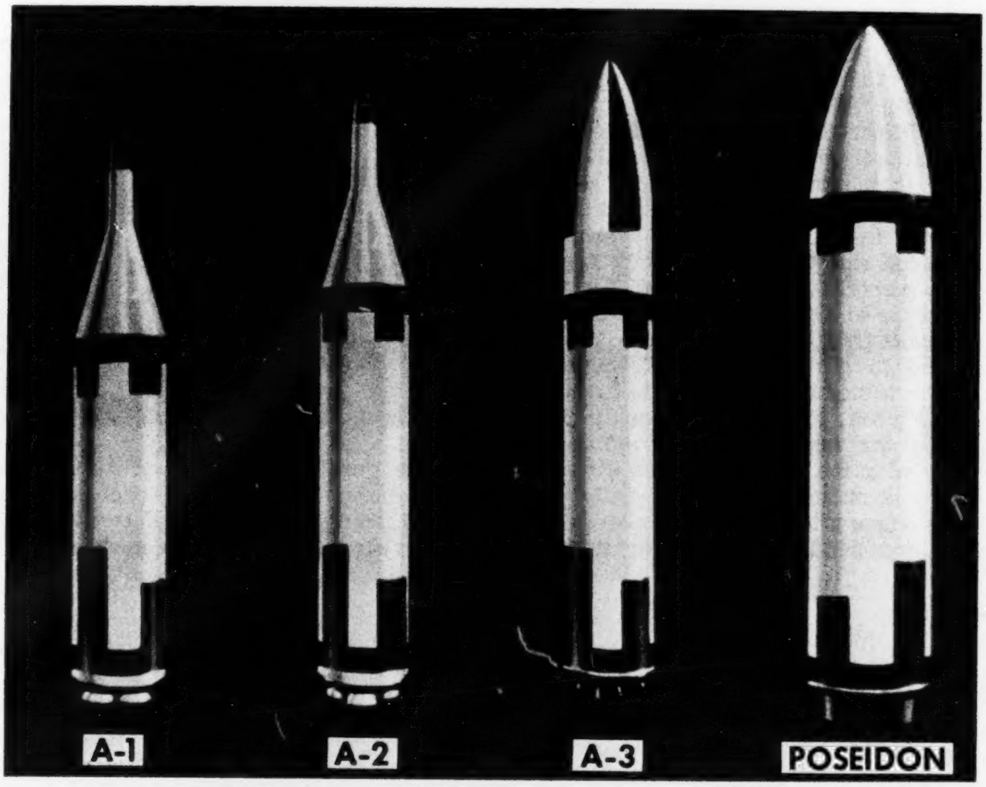


FBM SUBMARINE

In 1967, the force of 41 FBM submarines with their 656 POLARIS missiles became available. Fully two-thirds of the deployed force will be at sea at all times. Each nuclear-powered submarine's 16 nuclear-tipped missiles are zeroed in on strategic targets. The heart of the submarine's navigation system is SINS (Ship's Inertial Navigation System). A gyroscopic frame of reference is established with SINS stable platform, maintaining a constant report of the ship's position. SINS is updated from other navigation aids including the Navy's satellite navigation system. During the time the missile is in flight, a computerized fire control system accounts for ship's position, target location, true north, submarine motion, and even the amount of the Earth's rotation. The fire control system erects and aligns the missile's inertial guidance system, provides exact steering instructions, and can prepare missiles for launch faster than one missile per minute.



A fourth generation missile, POSEIDON, now being developed, is a new missile which will give the fleet greater accuracy and greater payload.

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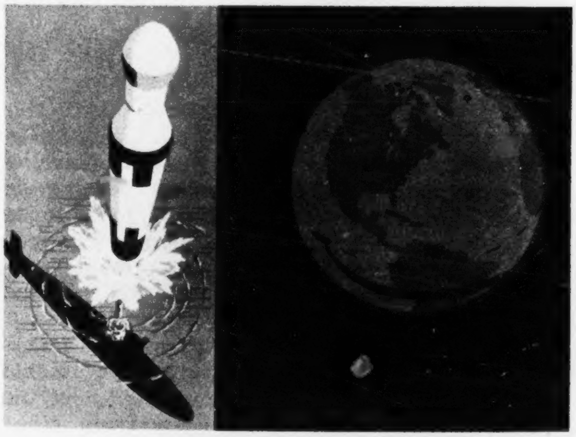
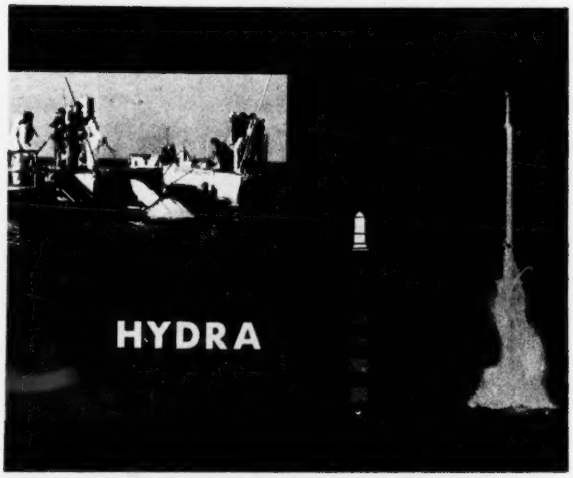
As space boosters become larger and larger (beyond SATURN V) limitations of real estate and added safety precautions may require launch sites at sea. The concept of launching at sea from ships or submarines has already been proven. The open sea can provide sites directly on the equator for launching synchronous satellites thus eliminating the added thrust required for doglegging the satellites into equatorial orbit from the latitudes of the national ranges. Because over two-thirds of the Earth's surface is covered with water, many unique locations for high-altitude research can be reached best by ships.



The suggestion of launching rockets from the surface of the oceans originated in 1923, when Herman Oberth proposed that large rockets could be towed out to sea, erected by fueling with alcohol and liquid-oxygen, and then be fired. In 1929, Oberth was technical advisor in a German science-fiction film titled, "Woman in the Moon" which showed such a simulated water launch of a large rocket.

In 1960, work at the Naval Missile Center at Point Mugu, Califormia, led to project HYDRA, which demonstrated the feasibility of launching small and medium rockets from the water. HYDRA is a launch site concept, not a missile or vehicle system. It is simply a short name for mobile sea-launching from a free-floating position on the open ocean. It can be compared to NASA's gantries or the Air Force's silos before missiles are put into them.



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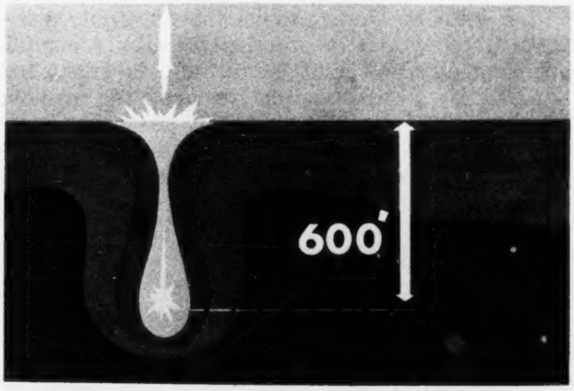

Theoretical studies show that there are no major technical problems in adapting present solid-propellant missiles, or building new liquid-fueled vehicles, to be HYDRA-launched. The fueled-vehicles when in the water act like spar buoys. The larger the vehicles, the more stable they are in the water - just like icebergs. When the vehicles are launched, the initial departure vector is very close to the vertical. Theoretically, it should be possible to fire boosters from water depths as great as 600 feet.

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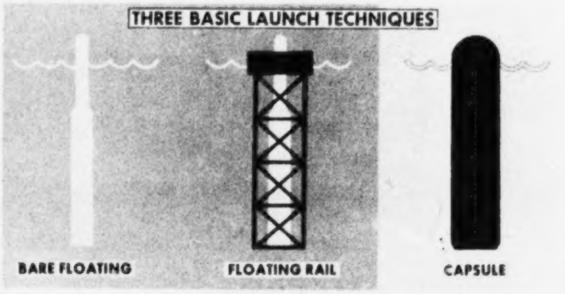
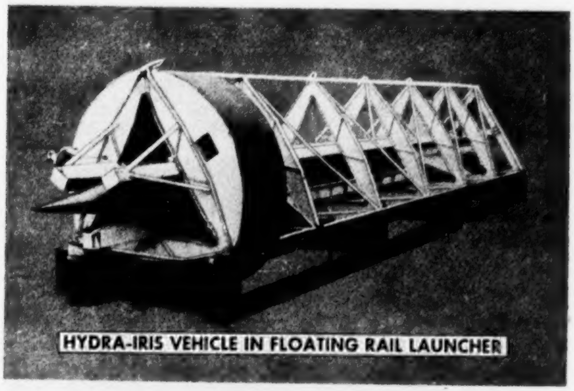
The sea-launch method is particularly attractive for launching large chemical and nuclear boosters of the future. The Naval Missile Center has investigated three basic-water-launch techniques:

(1) Bare-floating. Except for buoyancy aids and damping fins which separate at the moment of launch, the rocket floats unsupported. Most of the vehicles launched in the HYDRA project belong to this category.

(2) Incapsulated. The rocket is contained in a tube for transport and launch. This method might be used for sounding rockets and for other missions requiring long-storage and considerable handling.

(3) Floating rail launcher. The rocket is held between multiple rails suspended from a flotation chamber. This technique provides high-stability and structural support in an active sea. Such launchers have been successfully used for launching ARCAS, CAJUN and HYDRA-IRIS.





During the launch sequence, the booster and the sustainer are ignited almost simultaneously, and as soon as the booster thrust level decreases to a sufficiently low-level, the IRIS leaves the interstage ring and pulls away from the booster on its upward trajectory.

In January 1965, a HYDRA-IRIS vehicle was fired from a floating-rail launcher in the open ocean, east of Buenos Aires. The vehicle lifted a 125-pound gross payload to an apogee of about 155 nautical miles. This is where a magnetic anomoly allows the Van Allen Radiation belt to dip into the atmosphere. The Officer-in-Charge of the Space and Astronautics Orientation Course (SAOC), Commander R. G. Herron, had an experiment for the first proton measurements in a vertical rise profile in this payload.

Several of the instrumented test vehicles that have been launched under the HYDRA project during the research and development phase include: a solid-fueled HYDRA 1A; a 105-foot telephone pole to test rocket ignition at this depth below the surface; the HYDRA-ARCAS; and a liquid-fueled SEA BEE.

HYDRA-IRIS is a current workhorse for boosting scientific payloads into space. The main components of the HYDRA-IRIS are:

1. A two-stage unguided rocket vehicle.
2. A floating rail launcher.
3. A remote (radio link) checkout and vehicle function control system.

Final assembly, checkout, and launcher loading are done aboard ship. The ship's boom is used to place the vehicle and launcher combination into the water where the assembly automatically assumes the vertical position. A remote checkout verifies that the vehicle is ready for launch. If a malfunction occurs, the remote checkout link can return the assembly to a "safe" condition so divers can make the propulsion systems safe for retrieval by the launch ship.

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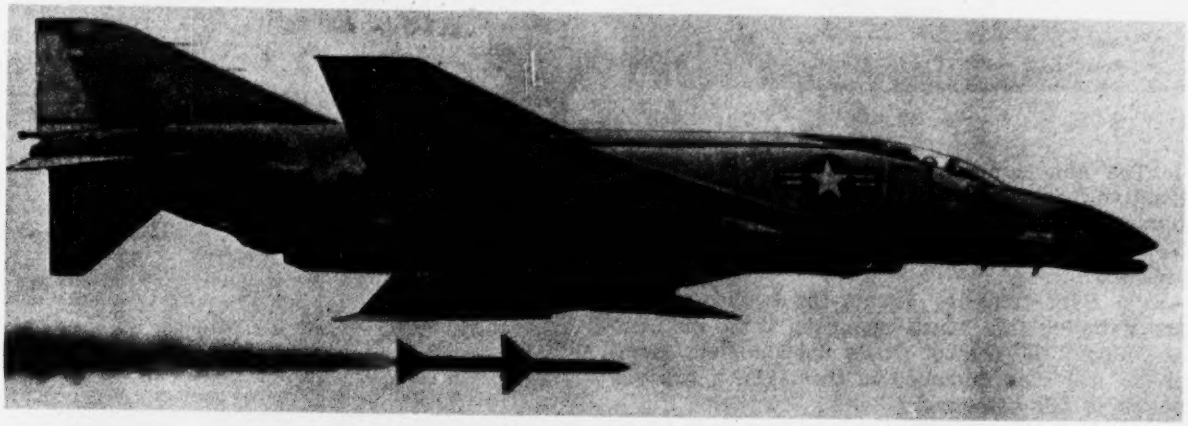
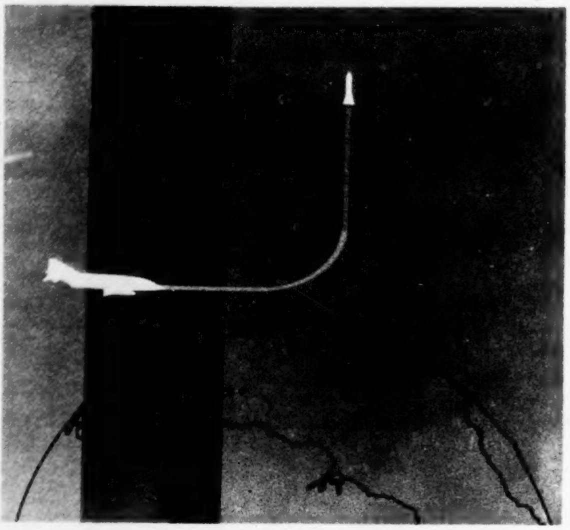


AIR LAUNCH

Military aircraft have launched air-to-air and air-to-ground missiles since World War II. In 1957, during the International Geophysical Year, ROCKOONS were launched from ballons and atmospheric sounding projectiles. The ROCKOON was designed to carry a 25-pound payload to an altitude of 70 miles. The ROCKAIRE was designed to carry a 40-pound payload to a 40-mile altitude. These were both solid-propellant missiles.

In 1960, the Navy launched a payload of over 150 pounds from an F4B aircraft in an over-the-shoulder delivery by using a two-stage missile. The missile was launched vertically at 36,000 feet, rose to a 630-mile apogee and arced down-range 730 miles. The technique of using missiles with one, two, or three stages of propulsion was attractive from standpoints of flexibility and economy because the aircraft acted as the recoverable first stage booster.

The Air Force is developing an air-launched, air-recoverable rocket (ALARR) as part of the VELA-surface detection system for monitoring nuclear activities in the atmosphere. F-4 aircraft are used for launching the modified GENIE rocket, and C-130 aircraft are used for recovering the nosecone in the air while the nosecone is slowed in its descent by a ballute and parachute system. The launches are at supersonic aircraft speeds with nosecone apogees of 250,000 feet. The aircraft (flown at 39,000 feet and at Mach 2) initiates a pull-up which exerts 3½ g acceleration and the rocket is launched at an angle of 70 degrees from horizontal.



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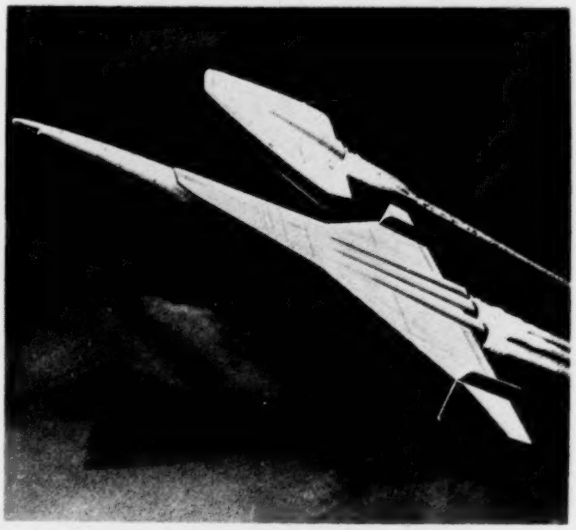
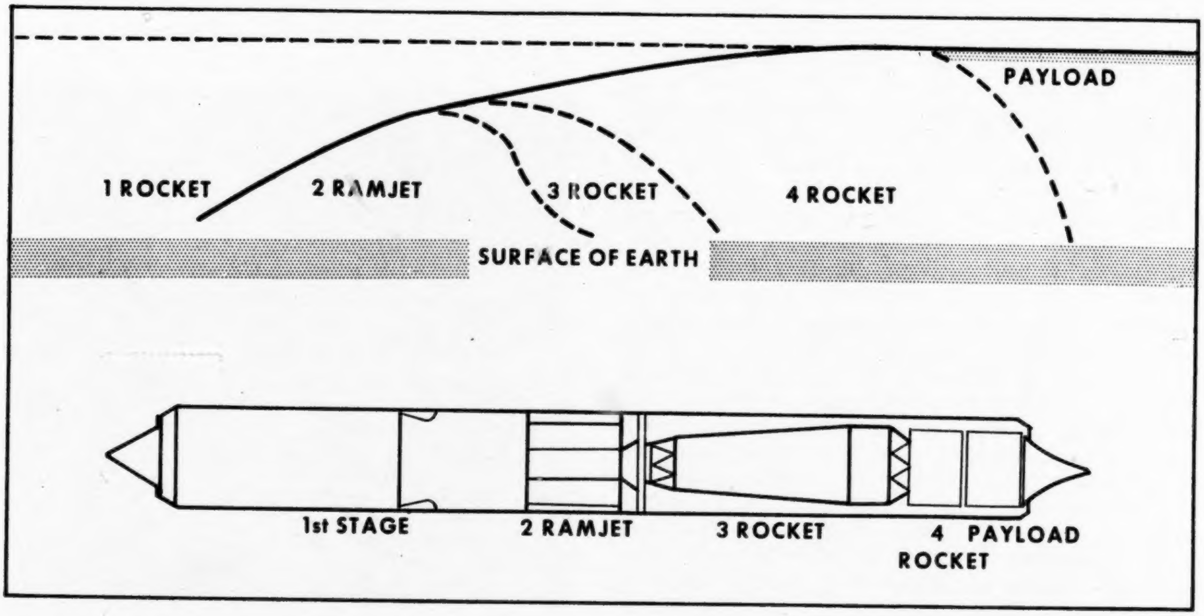


Launching by a recoverable RAMJET-powered second stage, boosted to operating velocity with a surface rail-guided rocket engine as first stage, has been studied. By using air-breathing engines, an oxidizer is not required on board. Of the various air-breathing engines, SCRAMJETS (supersonic combustion Ramjets) are more efficient than conventional Ramjets at speeds over Mach 8.

The primary difference in the SCRAMJET and the RAMJET is the design of the inlet and convergent-divergent nozzle. In the SCRAMJET incoming air is slowed to supersonic speed before fuel is injected and burned, maintaining supersonic flow. In the RAMJET, incoming air is slowed to subsonic speed at the inlet, fuel is injected and burned, and the outlet products are accelerated in a convergent-divergent nozzle. The main disadvantage of these engines is the requirement to boost them to operating velocity.



One method studied to place a vehicle into orbit about the Earth proposed: (a) to boost the RAMJET-powered second stage to operating velocity along the ground with a rail-guided rocket engine, (b) to fly the RAMJET-powered second stage to its maximum velocity and altitude, and (c) to complete the ascent of the payload to orbit with rockets.

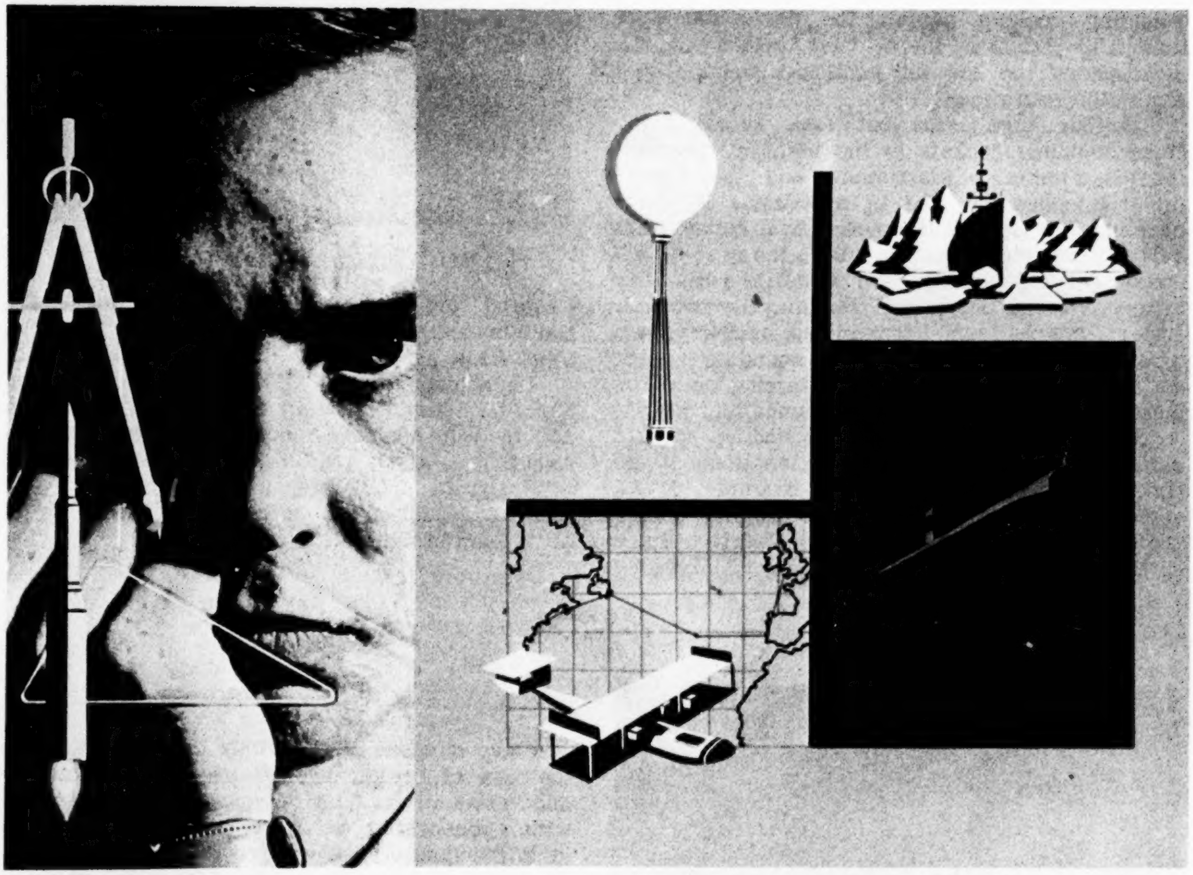
In the study, a four-stage vehicle was proposed for the mission. Orbital payloads of 500 and 1000 pounds were considered for launching from a north-to-south track to an orbital altitude of 50 nautical miles. Rockets would comprise the first, third, and fourth stages; the RAMJET would be the second stage. The ascent trajectory is shown for the planned mission.

The first and second stages would be recoverable. The proposed launch site was a north-south track at Point Arguello in the Western Test Range.

With this background of present and future launch techniques, let us proceed to a detailed consideration of the programs and vehicles used to gather data in space.

CHAPTER 12

DATA GATHERING IN SPACE



GENERAL

The impetus to discover and analyze the environment surrounding Earth has encouraged man to gather data from space by any means available. At the turn of the 20th century, DeBort used balloons to obtain quantitative data on the physical characteristics of the troposphere. The next decades saw a great harvesting of knowledge about the stratosphere. The advent of rocketry led to even more frequent and deeper sounding of the air ocean. Rocket societies were organized in many countries to work with sounding rockets. In 1930, for example, the American Interplanetary Society, the predecessor to the current American Institute of Aeronautics and Astronautics (AIAA), was formed.

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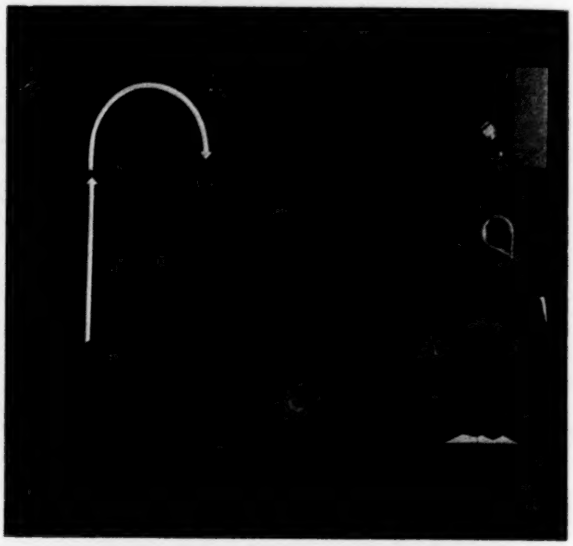

Generally speaking, sounding rockets are designed to attain altitudes up to about 4,000 miles and return data by radio telemetry or capsule recovery. Those probes designed for lower-altitudes generally investigate geophysical properties of the upper atmosphere surrounding the Earth. These have returned information on atmospheric winds, the Earth's cloud cover, and properties of the ionosphere. Higher-altitude sounding rockets have sent back data on cosmic rays, radiation belts, ultraviolet rays, solar flares, and many other phenomena. Sounding rockets permit the performance of scientific studies in a vast region of the atmosphere too low for satellites and too high for balloons to reach.

Another significant but less known value from sounding rockets is the in-flight development and testing of instruments and other equipment intended for use in satellites. By first checking out the performance of these components during sounding rocket flights in the near-Earth space environment, greater satellite reliability is assured and costly failures may be avoided. Experimenters from universities, industry, and foreign organizations use the sounding rocket as a logical and inexpensive starting point for gaining experience in space science techniques.

Another attribute is that sounding rockets carry instruments to specific locations at the time and place needed. For example, NASA sounding rockets (Nike-Apache flights during September 1967) teamed with Puerto Rico's Arecibo Ionospheric Observatory to probe the Earth's ionosphere in three launches from the Vega Baja Airport near San Juan, Puerto Rico.

Launching from this Caribbean location permits simultaneous comparison of data acquired by the NASA sounding rockets and by Arecibo's giant radar-radio telescope, 30 miles from the Vega Baja launch site. The Arecibo radar-radio telescope is the largest of its kind in the world.

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SCIENTIFIC PROBES

Navy support of upper air research through the use of rocket probes has been consistent and productive. This support began in 1946 with sponsorship of twelve German V2 flights at White Sands Proving Grounds. These experiments were followed by the AEROBEE shots in 1947 under Navy cognizance. AEROBEE launchings included the solar beam experiment program to monitor background radiation from the Sun during quiet periods of solar activity; studies of ultraviolet radiation of the stars and nebulae; gamma radiation studies; and many other scientific programs. Other sounding rockets were used for space experiments ranging from the study of weather to detection of the faint ultraviolet rays from distant stars.

In 1951, fleet requirements for a high-altitude sounding rocket caused the Navy to support a High-Altitude Scientific Program (HASP). As part of HASP, a small 25-pound LOKI rocket (an early Army anti-aircraft weapon) was modified to carry an elongated DART payload containing chaff (metallic reflectors useful in radar tracking). The vehicle was fired from a launching tube atop a gun barrel and subsequently from the gun itself by using bore riders. The chaff is carried to 100,000 feet by the rocket and dispersed. The chaff is then tracked by radar to determine wind velocities in the upper-atmosphere.

Another Navy single-stage probe is the ARCAS developed by the Office of Naval Research to be used initially for soundings up to 200,000 feet. These small meteorological sounding rockets provide information about the atmosphere at altitudes from about 20 to 40 miles. The rockets eject chaff, parachutes, inflated spheres, and bead thermistors at the highpoints of their trajectories. Collectively, these devices provide information about the atmospher as they fall to Earth. (The bead thermistor is in a package that telemeters temperature information to Earth. The chaff, parachute and inflated sphere are tracked to provide velocity information on winds. The rate of fall of inflated spheres also provides information on air density.) The portable ARCAS launcher weighs 400 pounds and can be rigged by two men in less than two hours. Altitude and payload capabilities have been improved by the addition of a SIDEWINDER motor as a booster which propels the ARCAS to altitudes in excess of 400,000 feet. On 30 May 1965, ARCAS sounding rockets were used in conjunction with high-flying jet aircraft, instrumented balloons, and ground-based observatories to study a solar eclipse.

An eclipse presents an unusual opportunity to view the Sun's atmosphere, or corona, which is normally masked by bright sunlight. In addition, scientists can examine the Earth's upper atmosphere, particularly the ionosphere, when solar radiation is abruptly curtailed.

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Significant scientific discoveries made by study of data from sounding rockets include the fact that temperatures in the mesosphere (an atmospheric layer 20 to 50 miles above Earth) are as much as 60 degrees higher in winter than in summer. Rockets have also provided evidence of pronounced wind shears at altitudes above 40 miles. (Wind shears refer to shifts in wind direction from altitude to altitude.)

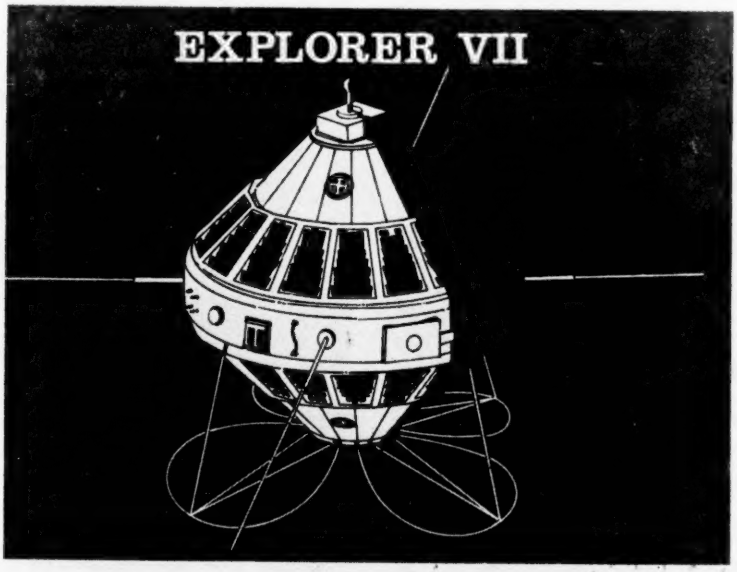
The Army's NIKE, with additional stages, has been employed frequently in upper atmosphere experiments. In one type of these experiments a series of small grenades are ejected and exploded at intervals along the rocket's trajectory. The locations of the explosions are determined by radar and/or optical methods, and the time of arrival of the sound wave front at the ground is measured by microphones. This information, with appropriate meterological data on the lower-altitudes, indicates wind and temperature as a function of altitude. Another type of experiment releases a sodium vapor trail at twilight which glows orange along the upper portion of the rocket's trajectory. The deformations of this trail are recorded on time lapse photographs and wind information is derived. A third method is the pitot-static tube experiment by which atmospheric density, temperature, and wind data are derived from direct measurements of pressure during flight of the rocket.

Sounding rockets have recorded the lowest temperatures ever measured in Earth's atmosphere. U.S. - Swedish cooperative sounding rocket studies conducted from Swedish Lapland found temperatures as low as -143 degrees Centigrade (-225 degrees Fahrenheit) in the upper atmosphere. The studies also solved the mystery of noctilucent clouds. Such clouds, existing at altitudes of about 60 miles, are peculiar because they shine at night. They are now believed composed primarily of ice-coated dust particles.

If instrumented payloads surpass 4,000 miles in altitude they sometimes are labeled geoprobes. Examples of geoprobes are the Probe-21 (launched 19 October 1961) and the Probe-21A (launched 29 March 1962) to measure ionosphere characteristics by day and by night. Both were carried to about 4,200 miles altitude by NASA SCOUT launch vehicles. Results indicated the existence of a helium gas region in the atmosphere wedged between a region where oxygen predominates and a higher one where hydrogen predominates. Explorer VIII, launched 3 November 1960, had provided the first indication of this helium layer.

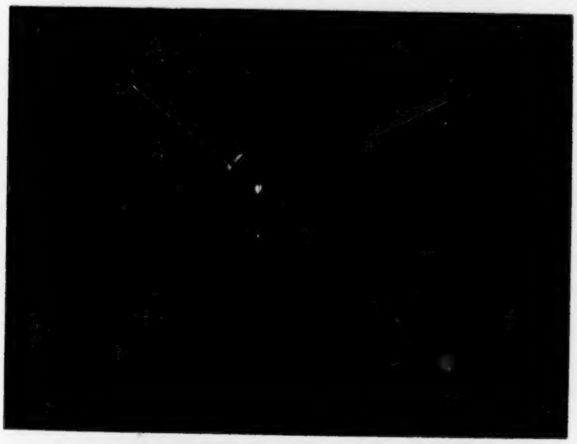
SATELLITE PROGRAMS

Although sounding rockets, equipped with various kinds of instruments, are basic to probing the environment of Earth, we will now describe their big brothers, the scientific satellites, and present some advances in knowledge that they have made possible.



EXPLORERS

Explorers comprise the largest group of satellites in the United States space program. Explorer I, launched February 1, 1958, was the Nation's first satellite. It made one of the most significant contributions of the Space Age, confirming existence of the previously theorized Van Allen Radiation Region (a zone of intense radiation surrounding the Earth). Generally, Explorers are small satellites carrying a limited number of experiments. Explorers have been put into orbit to measure the thin wisps of air in the upper atmosphere, and to determine air density by position and altitude. For example: Explorer XXIV provided data on the composition of Earth's ionosphere, including the presence of electrons which cause radio waves to be bounced back by the ionosphere, thus making possible long-range high-frequency radio communications on Earth. Explorer XXXI studied the composition, density, pressure, and other properties of the upper atmosphere and provided information on micrometeroids (tiny particles of matter speeding through space). Explorer XXIII measured the small variations in Earth's gravity field and fixed more precisely the locations of points on Earth.



VANGUARD

Project Vanguard, now successfully completed, was inaugurated as part of the American program for the International Geophysical Year (IGY). The first Vanguard satellite went into orbit on 17 March 1958.

Among the valuable data acquired from this satellite was information regarding the small but significant distortion referred to as the "pear shape" of the Earth. Two other Vanguards were launched in 1959. Vanguards have provided valuable information on Earth and its space environment, including such phenomena as Earth's magnetic field, the Van Allen Radiation Region, and micrometeoroids.

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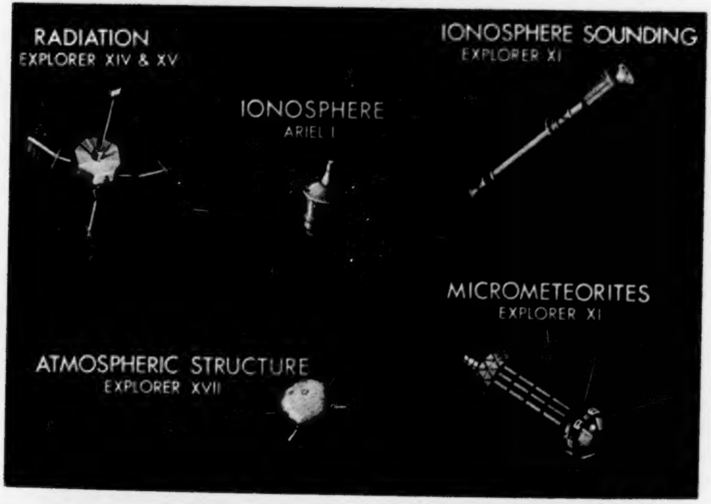
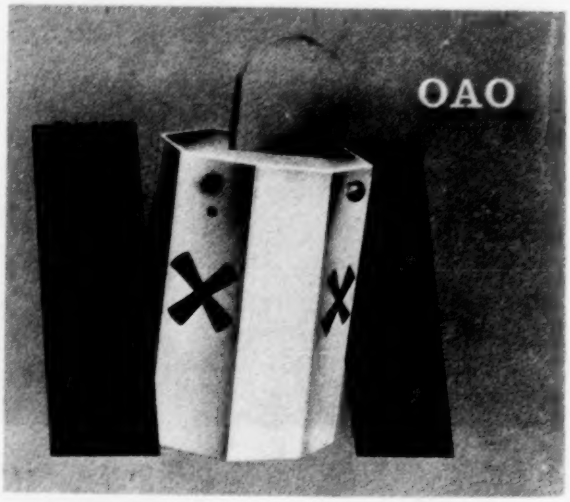


INTERPLANETARY EXPLORERS

Interplanetary Explorers are a special class of Explorers to provide data on radiation and magnetic fields existing between the Earth and Moon. The information will be essential to planning for the APOLLO program to land American Astronauts on the Moon. The first interplanetary Explorer, named Explorer XVIII, provided data indicating that the Earth's magnetic field was shaped more like a teardrop than like the familiar symmetrical cluster of iron filings around a bar magnet. The Earth's magnetic field apparently is pushed into this kind of shape by the solar wind, which consists of hot electrified gases rushing from the Sun's surface. The impact of the speeding solar wind against the Earth's magnetic field was shown by Explorer XVIII data to produce a magnetic shock-wave. Interplanetary Explorers are planned for launch into orbit around the Moon. These spacecraft will measure gravity, radiation, magnetic fields, micrometeoroids, and other phenomena in the lunar environment. This information, too, will advance both scientific knowledge and planning for manned exploration of the Moon.

ORBITING ASTRONOMICAL OBSERVATORY (OAO)



Man's study of the universe has been narrowly circumscribed because the atmosphere blocks or distorts much electromagnetic radiation (X-rays, infrared rays, ultra-violet rays) from space. These emissions can tell much about the structure, evolution, and composition of celestial bodies. The OAO will make it possible to observe the universe for extended periods from a vantage point well above the shimmering haze of the lower atmosphere. OAO will see celestial bodies shining steadily against a black background. It will clearly delineate features which from the Earth are either fuzzy or indistinguishable.

OAO will be a precisely stabilized 3900-pound satellite in a circular orbit about 500 miles above the Earth. It will carry about 1,000 pounds of experimental equipment (telescopes, spectrometers, and photometers) supplied to NASA by leading astronomers. The standardized OAO shell will be employed for many different types of missions and will contain stabilization, power, and telemetry systems. Two silicon solar-cell paddles and nickle-cadmium batteries will furnish an average usable power supply of 405 watts. The satellite is about 11 feet wide with solar paddles extended and the width of the main body is nearly 7 feet. OAO will be an unobstructed peep-hole into the universe.

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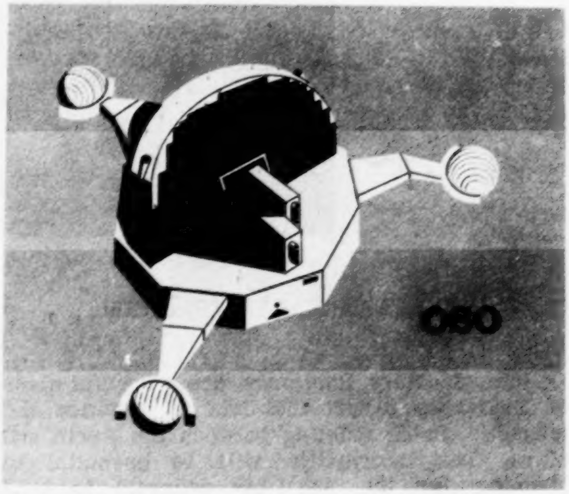
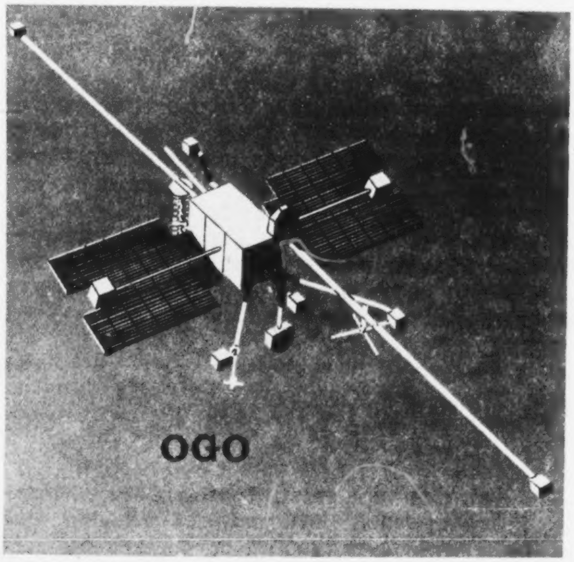
ORBITING SOLAR OBSERVATORY (OSO)



OSO is a series of satellites intended for intensive study of the Sun and solar phenomena from a point above the disruptive effects of the atmosphere. The observatory is designed to carry such instruments as X-ray and Lyman Alpha spectrometers, neutron flux senors, and gamma-ray monitors. Like OAO, OSO scientific equipment is supplied NASA by leading astronomers.

The first of these observatories, OSO I, which was about 37 inches high and 44 inches in diameter at the wheel-shaped section, was launched 7 March 1962. From a circular orbit at an altitude of about 350 miles the 440-pound spacecraft was able to point instruments at the Sun with an accuracy of 5 seconds of arc. This is comparable to sighting a penny a half mile away with a rifle scope. Data from OSO I have provided deeper insight into the functioning of the Sun, and suggest that techniques could be developed for forecasting the major solar flares that flood space with intensities of radiation lethal to man and detrimental to instruments. OSO II, with an added capability for scanning the solar disc, was launched on 3 February 1965 to continue scientific studies of the Sun.

ORBITING GEOPHYSICAL OBSERVATORY (OGO)



Orbiting Geophysical Observatories gather significant knowledge about the Earth, space, and how the Sun influences and affects both. The 1000-pound OGO furnishes many times the data provided by smaller scientific satellites such as the Explorers. For example, OGO I (launched 4 September 1964) and OGO II (launched 14 October 1965) carried 20 different experiments as compared to the relatively few experiments of Explorer XVIII (eight experiments).

The principal advantage of OGO is that it makes possible the observation of numerous phenomena simultaneously for prolonged periods of time. This permits study in depth of the relationships between the phenomena. For example, while some OGO experiments report on the erratic behavior of the Sun, others may describe concurrent fluctuations in Earth and interplanetary magnetic fields, space radiation, and properties of the Earth's atmosphere.

OGO is launched on a regular schedule into pre-assigned trajectories. When launched into an eccentric orbit (apogee about 60,000 miles, perigee about 150 miles), OGO studies energetic particles, magnetic fields, and certain other geophysical phenomena. When launched into a low-altitude polar orbit (apogee about 300 miles, perigee about 140 miles), OGO is instrumented chiefly for study of the atmosphere and ionosphere, particularly over the poles.

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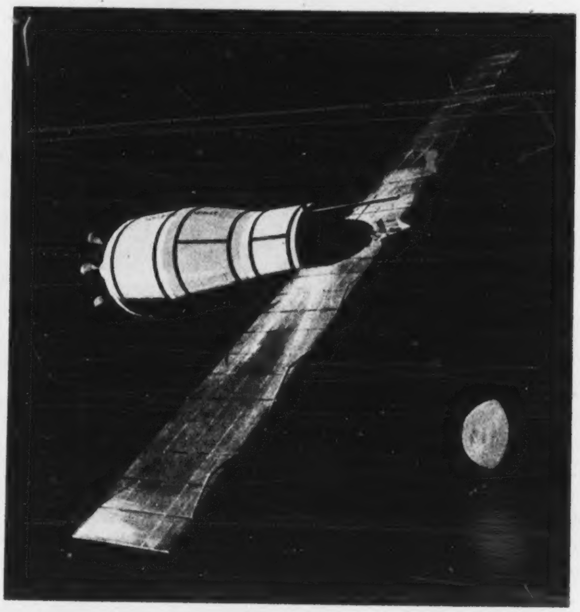
PEGASUS

Named for the winged horse of Greek mythology, Pegasus satellites are among the heaviest and largest U.S. spacecraft. Deployed in space, the great wings of the Pegasus satellites span 96 feet while the center section, resembling the fuselage of an airplane, is 71 feet long. The wings are designed to report punctures by micrometeoroids. Data from Pegasus satellites not only have advanced man's understanding of space but are aiding him in design of large craft intended for prolonged missions in space. For example, the depth and frequency of penetrations reported by Pegasus satellites help engineers to design the walls of spacecraft.

The Pegasus satellites present about 80 times the surface that was exposed to particle impact by previous meteoroid study satellites such as Explorers XVI and XXIII. The three satellites in the Pegasus program were launched by SATURN I rocket vehicles on February 16, May 25, and July 30, 1965.



BIOSATELLITES

Biosatellites carry into space a wide variety of planets and animals ranging from microorganisms to primates. The experiments are aimed primarily at studying the biological effects of zero gravity or weightlessness, weightlessness combined with a known source of radiation, and removal of living things from the influence of the Earth's rotation. They are expected to contribute to knowledge in genetics, evolution, and physiology, and to provide new information about the effects of prolonged flight in space.

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DISCOVERER

Discoverer is a satellite program that, since 28 February 1959, has provided valuable data in such areas as radiation, meteroids, and air density in space near Earth, and in aerospace medicine. A major contribution of the program was the development of the technology for midair recovery or sea-recovery of packages sent from an orbiting satellite to Earth.

The first sea-recovery was a package from Discoverer XII which was returned on 11 August 1960. The first mid-air recovery of a package ejected from a satellite, (the 300-pound recoverable package had been ejected from Discoverer XIV) took place on 18 August 1960. Discoverers have also tested components, propulsion, guidance system, and other technology for space projects. The Discoverer program was a major factor in testing and perfecting the Agena rocket, the reliable upper stage for many launch vehicles.

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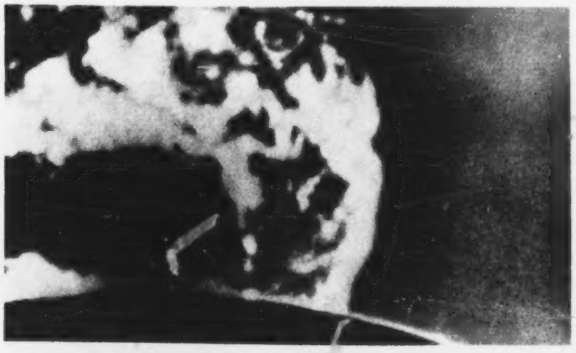


SOLRAD

Solrad is an acronym for Solar Radiation Monitoring Satellite. The present objectives of Solrad are to (a) contribute to our understanding of the Sun and its intimate relation to our Earth environment, and (b) to detect increases in the Solar output of X-ray radiation which causes sudden ionospheric disturbances to occur. These X-rays are the precursor of HF radio blackouts which occur periodically on Earth.

The Navy has a particular interest in the possibilities this program presents as a Fleet warning technique useful in predicting these radio communication blackouts. In pursuit of information on solar effects, between the period 1949 and 1960, the Naval Research Laboratory successfully launched a series of rocket probes into the ionosphere. These probes were V2s, Aerobee, Rockoons (balloon rockets), Nike-Deacon, and the Nike-Asp. Rockets had their drawbacks, however; (1) they did not reach above the Earth's ionosphere, (2) they were not aloft for all phases of solar activity, and (3) they could not register time variations of the intensity of the X-ray and ultra-violet spectrum. To overcome these drawbacks, it was decided to launch a series of satellites. Beginning in 1960 and continuing to date, a series of eight satellites have been launched. Others are scheduled for launch in 1967, 1969, and 1970.

The use of these satellite systems to warn of impending communication blackouts will permit the fleet to respond by (a) moving to alternate unaffected frequencies, (b) using alternate means of communication, such as landlines or satellites, (c) rerouting radio message traffic early in order to prevent a bottleneck from occurring, and (d) reducing traffic volume by allowing only high-priority messages to be transmitted.

CHAPTER 13

SATELLITE COMMUNICATIONS

SATELLITE
COMMUNICATIONS

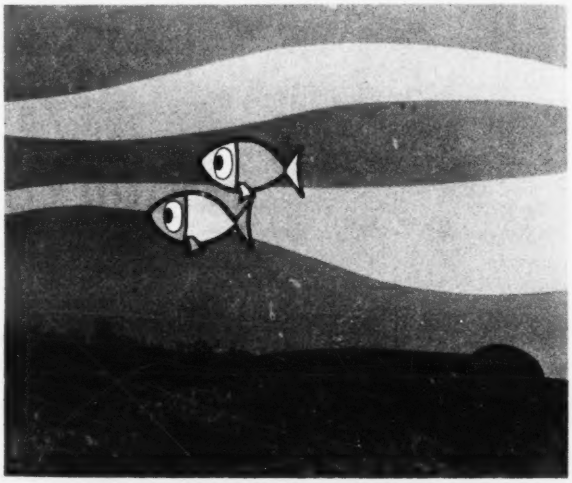
Satellites offer a means for greatly improved global communications. Communication via satellites has already proven successful beyond expectations and man is further developing this new technique for increased applications.

This chapter will review methods of long-distance communications and discuss some inherent limitations that might be overcome by the use of communication satellites. Key commercial and military satellite communication programs will be described briefly.

GENERAL

The history of communications is a history of man's increased understanding of his environment and his continuing attempts to master it. But, regardless of the heroic attempts taken thus far, an effective society requires better communications. One cannot help but be amazed at the progress that the communication media has experienced in the past century: in 1844, Morse demonstrated the first telegraph; in 1876 Bell created a practical telephone, and in 1896 Marconi's short-range communications. Finally, we are brought to the immediate past when reliable long-distance communications spanning continents have been conducted via radio waves and transmission cables, such as the telegraph and submarine cables.

While cables are very reliable, they are limited in data carrying capacity. Their terminal points are fixed, and the cables themselves are certainly vulnerable to damage. It has been estimated that a two-thousand mile cable system costs approximately four times that of a satellite system. Additionally, interruptions in communications due to sabotage or natural events (earthquakes, or undersea landslides) could have serious impact, especially during crises.



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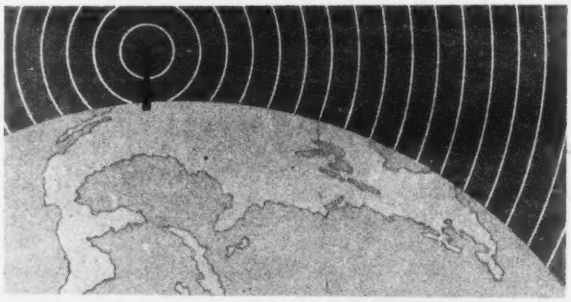
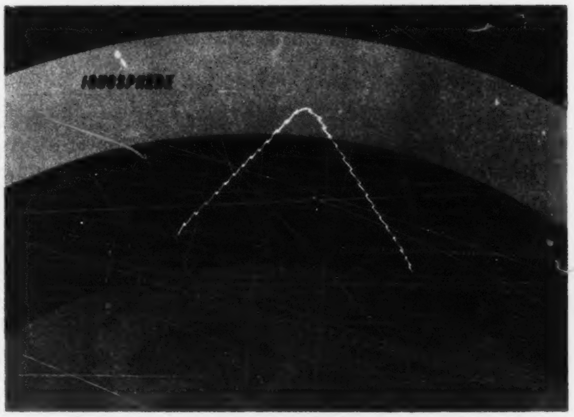
Radio has been the principle method of achieving long-distance communications. These transmissions are dependent upon a number of propagation factors. While not bound to the fixed trunk-line paths associated with cables, long-range high-frequency (HF) radio paths depend upon reflections by the ionosphere (constantly changing layers of charged particles blanketing the Earth from some 40 to 250 miles above the surface, see Chapter 2). Furthermore, the data handling rate of HF radio transmissions is limited by the bandwidth of the carrier frequency. Although voice and teletype may be transmitted on HF transmissions, video (television) or any high speed real-time digital data is severely limited or precluded.



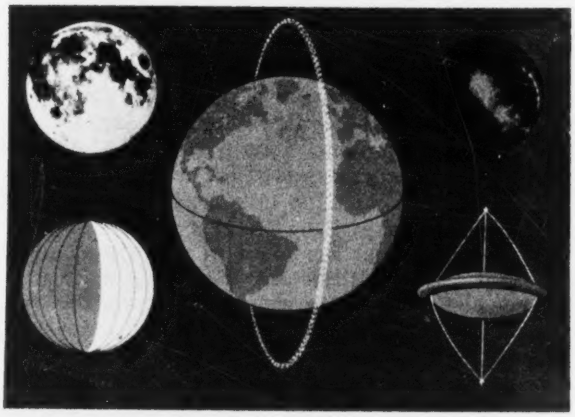
Very high frequencies (VHF) are characteristically in the MegaHertz (million cycles per second) region. These frequencies and the higher microwaves can accommodate higher data handling rates including video signals like television. But as television viewers in a fringe area know, these frequencies are limited to line-of-sight transmissions. With frequencies above 30-MegaHertz (the lower boundary of VHF), most of the energy transmitted passes directly upward through the ionosphere and is not reflected as lower frequencies. Hence, VHF and higher frequencies particularly are limited to line-of-sight transmissions ending at the horizon. For this reason our television links spanning the continent consist of microwave relay towers spaced every 30 miles or so across the nation.



SATELLITES TYPES

Communication satellites serve as radio relay stations in space.

They are designated as passive or active satellites based upon whether they merely reflect radio energy (passive) or actually generate radio energy (active). Passive satellites need no radio transmitter of their own since they reflect electromagnetic energy from their surfaces. Passive satellites include both large reflecting bodies (such as the Moon, the Echo Balloon Satellites, and certain wire mesh configurations), and distributed reflectors (such as the belt formed by millions of small copper needles placed in orbit in 1963 as part of Project West Ford). Passive reflector satellites with few components have a high reliability. Because these satellites do not amplify, only a small portion of the initial transmitted energy reaches the final receiving station. This method of relay requires large receiving antennas and expensive ground stations. Though studies and development of passive satellites continue, active satellites appear more promising for use as routine communication links in the immediate future.



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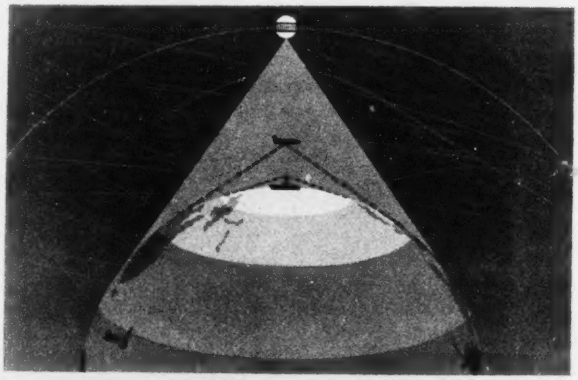
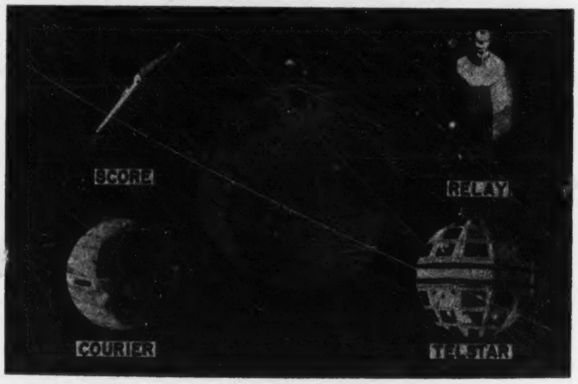
An active satellite receives, amplifies, and rebroadcasts radio signals. Consequently, active satellite equipment is more complex than a passive system. Active satellite repeaters (and we will deal with immediate retransmission rather than delayed repeaters) really perform a function similar to micro-wave relay towers. Because active satellites boost the energy level of the relayed signal, their associated ground stations need transmit less initial energy. Furthermore, because of signal amplification by the satellite, receiving stations may use smaller antennas. This is significant since small antennas may be carried within aircraft or located aboard ships.

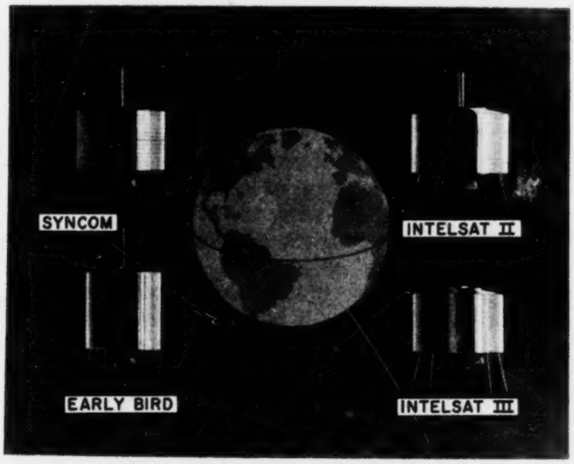


Active satellites may be conveniently grouped into two categories by their orbital altitudes: medium (below about 15,000 miles) and synchronous. Typical medium altitude active satellites include Project Score (launched in December 1958 by the Department of Defense as the first active satellite); Project Courier, (a time delayed, active satellite); the American Telephone and Telegraph Company's Telstar Satellites 1 and 2 (the latter, launched in 1963, provided the first trans-Atlantic two-way relay for television signals); and NASA's Relay satellites (launched in 1962 and 1964). Synchronous altitude active satellites (which orbit at 22,300 miles fixed in position over the equator) include Syncom II and



Syncom III, which were launched successfully by NASA in July 1963 and August 1964 (both are now carrying messages for the Department of Defense); the Communications Satellite Corporation's Early Bird (the first commercial satellite for space communications); the International Telecommunications Satellite Consortium (Intelsat) II series; and the commercial Intelsat III spacecraft which will be flown in 1968.

The arguments for medium altitude systems are that the satellites are less complex in auxiliary station keeping propulsion requirements (thus more reliable), and the lower altitudes provides higher overall system gain; while arguments for synchronous satellite systems are that the ground stations are simpler, and fewer satellites are required for global coverage. Generally, communications coverage of the Earth increases with satellite altitude. Three synchronous satellites equally spaced around the equator could provide continuous worldwide coverage, except near the poles.



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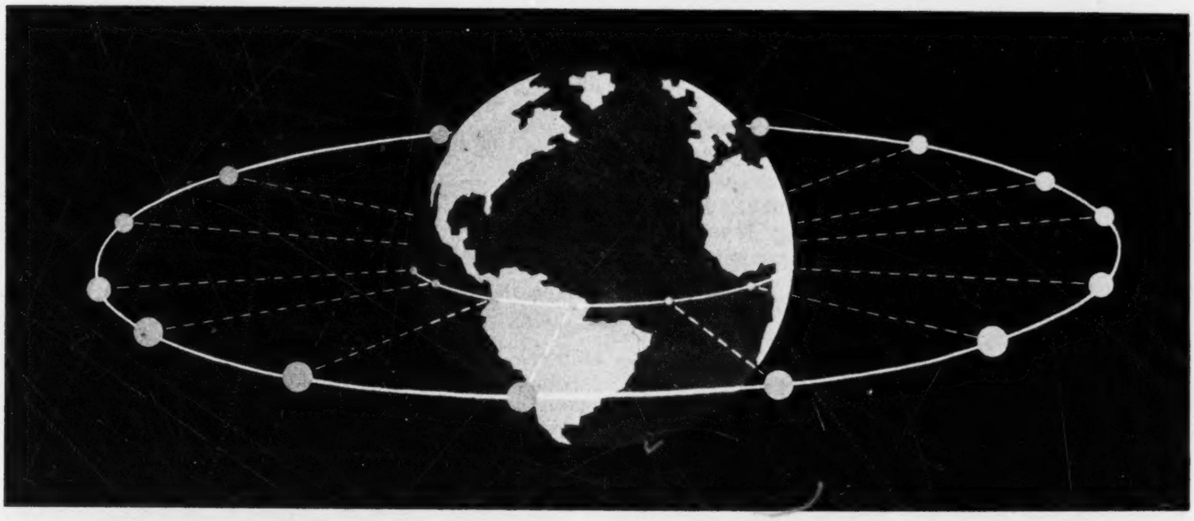
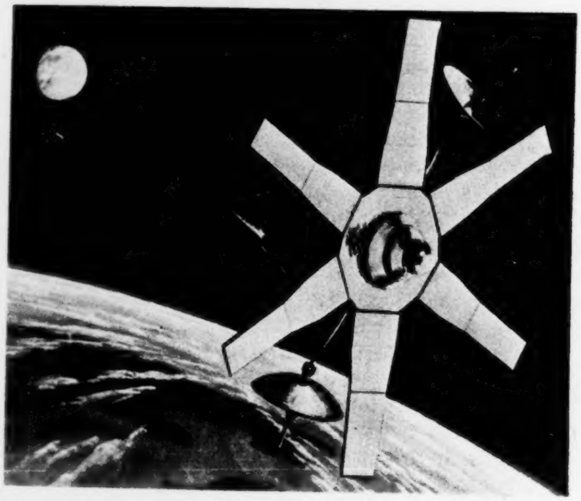


It should be borne in mind that a synchronous satellite requires not only sophisticated orbital position controls, but also complex power requirements and precise stabilized antenna pointing. Furthermore, a synchronous satellite is more susceptible to enemy interference or destruction because of its easily fixed location. Because of these susceptibilities, military authorities have favored a near-synchronous system, such as the current Initial Defense Communications Satellite Project (IDCSP). This system, flown in 1966, involves many satellites in slowly changing, randomly placed, near-synchronous orbits. The system provides effective worldwide coverage. The possibility of complete communication blackout for any geographic area is minimized since, unlike a synchronous system, the failure of a single satellite could be offset by an adjacent satellite that "walks" into view.

COMMERCIAL SYSTEMS

Commercial communications via satellites is mushrooming despite occasional problems of international agreement and competition among established commercial interests. The main stumbling blocks appear to be (1) in negotiating international agreements for the use of this new medium and (2) in the designing of multiple-access systems to satisfy countries with differing requirements for the channels. The Communications Satellite Corporation (COMSAT) has had a virtual government monopoly under the 1962 Communications Satellite Act to provide worldwide satellite communications. Incorporated in February 1963, this publicly-held company not only accrued slightly over 55% of the International Telecommunications Satellite Consortium (a group of over fifty cooperating nations), but became program manager for developing the space segments of the Intelsat global systems.



The USSR, which is not a member of this consortium, is the only nation, aside from the United States, to launch communication satellites. It has put up at least five since April 1965. These "Molniya" satellites (shown in the illustration) have been launched into elliptical orbits chosen to provide a maximum usage over the Soviet Union.

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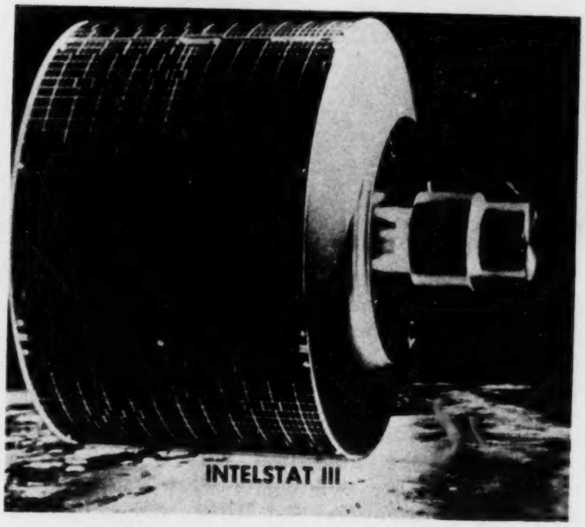


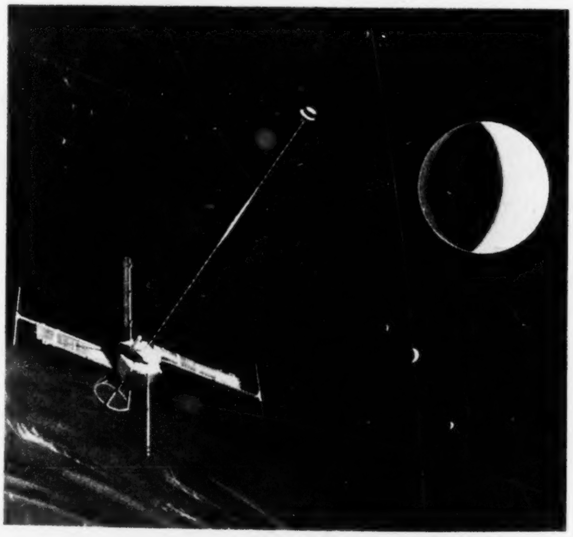
Today, the COMSAT systems include; the 85-pound Early Bird (Intelsat I) which was successfully launched during April 1965 aboard a three-stage Delta booster and placed into a synchronous orbit above the Atlantic; three of the Intelsat II series launched during late 1966 and early 1967 to provide commercial channels over both the Pacific and Atlantic Oceans and to provide links for the NASA APOLLO network; and the global Intelsat III series which is a multiple access, 1,200 channel satellite built for deployment in 1968. The Intelsat III will be synchronous, spin-stabilized, and will weigh in excess of 260-pounds. This satellite will derive power from solar cells and will employ a mechanically despun, phased array antenna.

The real growth in satellite communications apparently will come with these multiple access satellites which will permit many ground stations to use the satellite simultaneously. Certainly, increased requirements and higher data rates per user will tax available satellite power and bandwidth capabilities and lead to advanced designs for more multiple access satellites.

MILITARY SYSTEMS

Analysis by the DOD has demonstrated that maintaining military communication satellites for global coverage may prove less costly than maintaining long ground lines and submarine cables. While compatible commercial systems have been used by the DOD when appropriate, there are valid arguments for the existence of a separate military system. Important government messages should be carried independently of commercial traffic and should be immune from possible foreign intervention or control.

After a number of tentative experiments with communication satellites (such as Courier and Score) the military communications satellite program was revamped in 1962. Today, military emphasis is placed on three primary systems: the Syncom satellites, the Initial Defense Communications Satellite Project (IDCSP), and the Tactical Satellite Communication Program (TACSATCOM).



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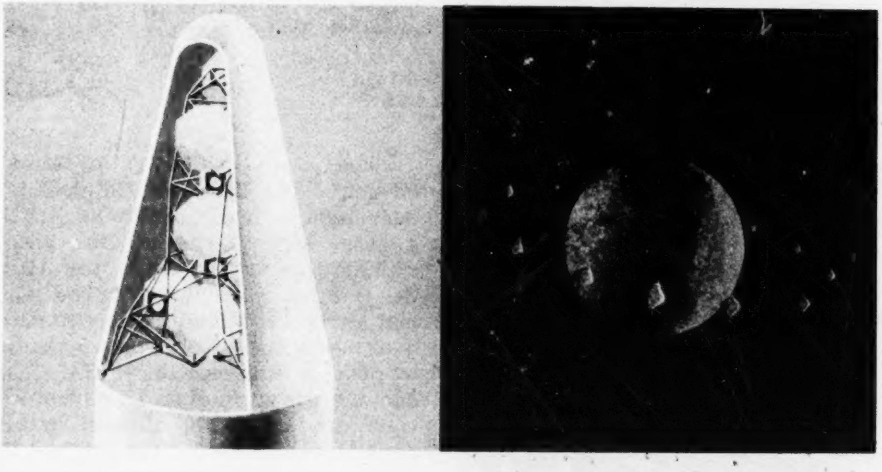
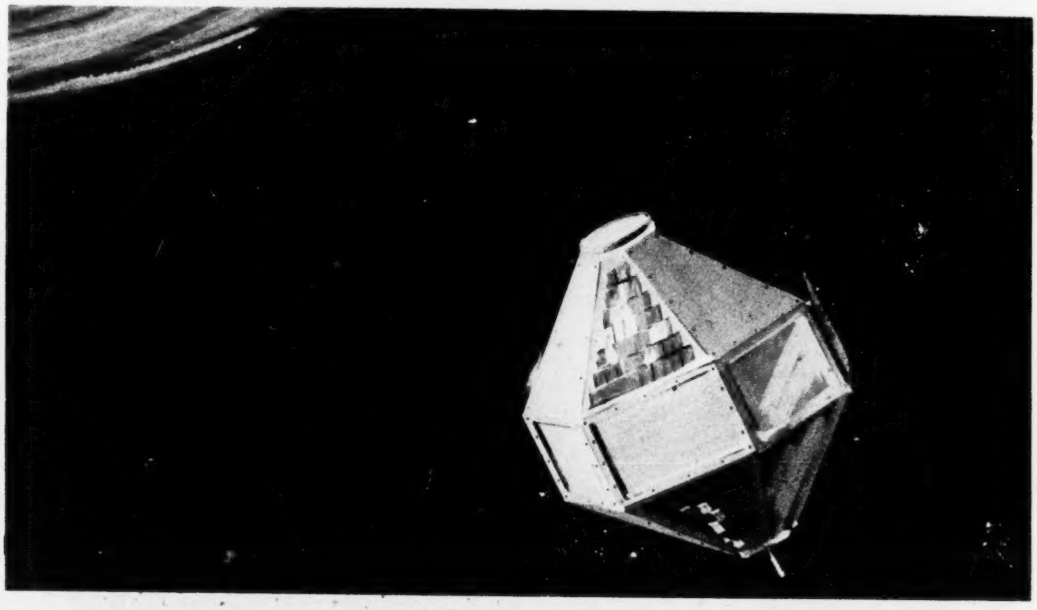


Actually, the IDCSP is an outgrowth of a medium altitude system which was to have 12 to 28 satellites circling at 6,000 miles in an uncontrolled random polar orbit. The 97-pound satellites for the IDCSP are launched from Cape Kennedy in the nosecone of a TITAN III-C. They currently constitute a part of a worldwide network that will ultimately consist of 19 to 27 satellites spaced in near-synchronous equatorial orbits in the vicinity of 22,000 miles. In such a random arrangement the distances between satellites constantly vary. Since these satellites are not at synchronous altitude, they drift slowly across the view of an Earth station at the rate of about 28 degrees per day. At this drift rate, an Earth station located at 35 degrees latitude can view the same satellite for about four and one-half days. Orbital periods of the satellites will differ somewhat causing the spacing between satellites to vary with time. The satellites will gradually drift past one another. However, orbital parameters may be chosen so that the satellites will never bunch.



The IDCSP satellites are spin-stabilized and operate at SHF (8 kilomegaHertz receive, 17 kilomegaHertz transmit) using a frequency-translation repeater. The antenna has a 25 degree look angle, which is sufficient to spread the energy over about a third of the Earth's surface. Because of its stabilization, a portion of the antenna beam will always be directed toward Earth. However, since the antenna is omnidirectional around the spin-axis, a large portion of the energy is also radiated into space. IDCSP satellites are now operating with several successful multiple launches to date.

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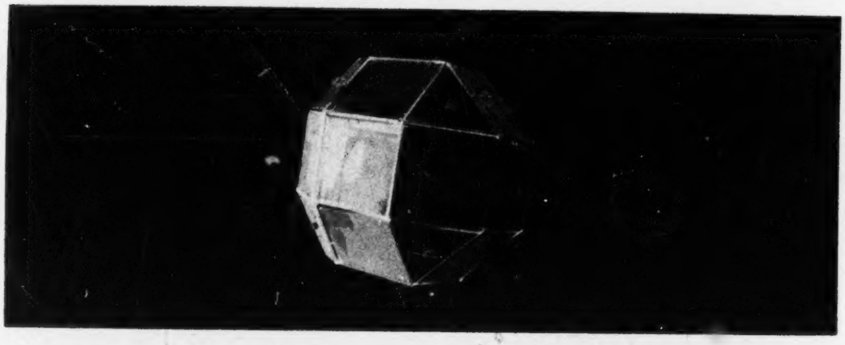
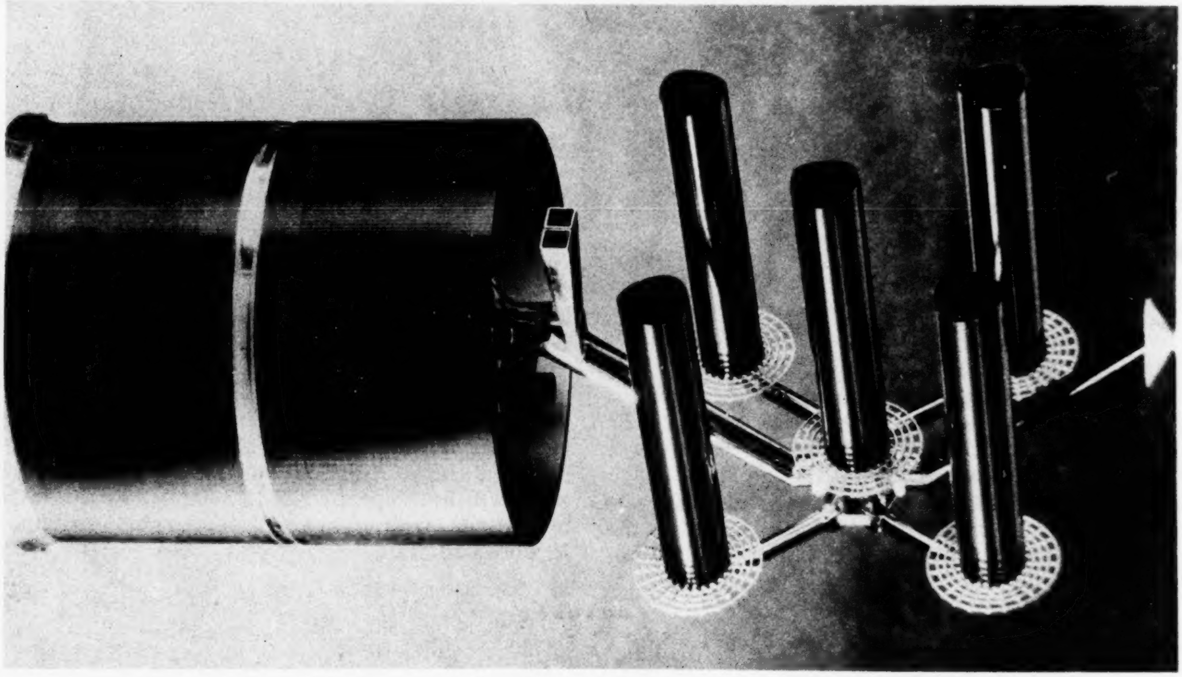


Of significant interest for military communications is the forthcoming Tactical Communications Satellite schedule to fly in 1968. This satellite, an outgrowth of earlier Lincoln Experimental Satellites, as shown in the illustration above, launched by the Air Force, will be the first tri-service communications satellite.

The prototype is being built under direction of the Air Force. The large five-element array for the tactical satellite consists of UHF antennas, each nearly eight feet long. Additionally, there are two microwave horns beneath the ultra high frequency antenna array and a biconical horn at the extreme end for telemetry and command. The satellite will be spin-stabilized at synchronous altitude. A rather unique feature is that the solar panels will be rotatable while the antenna and inner structure will remain in a stabilized position. The monopropellant reaction control system is being designed for an operational lifetime of five years.



Because of satellite communication systems, wholly new command, control, and usage capabilities for military and commercial communications is in existence. A breakthrough has been made into a new era of quickly available, worldwide communications. Communication satellites are now making a substantial contribution to our nation's ability to cope with emergencies wherever they occur. Space technology has brought our world even closer together as satellites transmit messages over the entire globe.

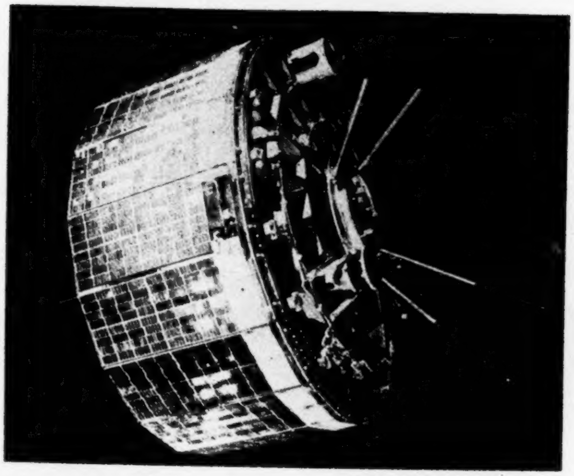
CHAPTER 14

SATELLITE OBSERVATIONS

METEOROLOGY SATELLITE OBSERVATIONS

The launch of the first TIROS (Television Infra-Red Observation Satellite) in April 1960 proved such a success and caused such enthusiasm that all interested agencies thought it advisable to have one National Meteorological System, and that satellite technology had advanced to the point where plans for such a system should be formulated.

The startling daytime cloud photographs from TIROS was the first step to an operational satellite system. Yet in order to observe changes in cloud formations more frequently, nighttime cloud pictures are also needed. The global coverage obtained by orbiting several satellites would also prove valuable in measuring many other meteorological parameters.



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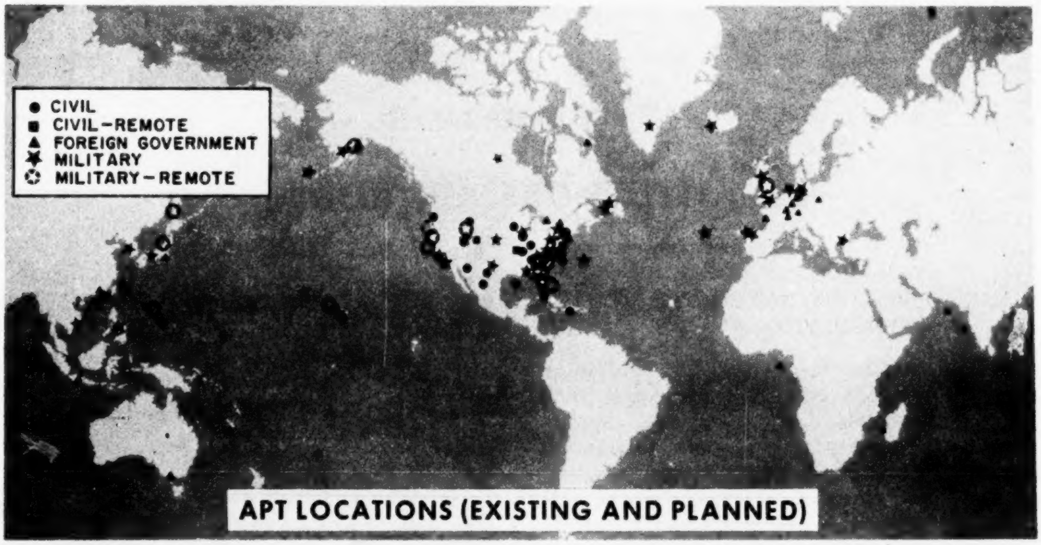
As guidelines to the specific data requirements to be placed upon the national system, three general objectives have been identified for the program through the middle 1970's; they are:

(1) To develop, establish, and operate a meteorological satellite system for periodic viewing of the atmosphere over the entire globe, regularly and reliably. This requirement includes the routine daily observation of the atmosphere over the entire world on a global basis both day and night. Further, an Automatic Picture Transmission (APT) system should be included to provide the opportunity for properly equipped stations at any location within radio range of the satellite to readout the weather in near real-time.

(2) To develop, establish, and operate a system of satellites for continuous viewing of worldwide weather features. Such a system will provide almost continuous viewing of the atmosphere over a large portion of the Earth, thus giving weather forecasters an opportunity to see cloud and storm movements as they occur.

(3) To develop, establish, and operate a system for sounding the atmosphere world-wide on a regular basis. The computer prediction systems now established to forecast atmospheric changes require that much more quantitative data be used in numerical analysis and prediction. The addition of certain data from spectrometric analysis of the atmosphere and other advanced technique should provide the opportunity to meet this third objective for obtaining quantitative information.

Recognizing that the requirements implied by the preceding statement of general objectives cannot yet be achieved, the principal agencies have agreed that interim operations should lead to those goals. Currently daytime cloud observations are achieved globally, and the Automatic Picture Transmission system for direct readout has been included. A nighttime capability for


● CIVIL
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▲ FOREIGN GOVERNMENT
✶ MILITARY
✪ MILITARY-REMOTE

APT LOCATIONS (EXISTING AND PLANNED)

cloud observation is under development and a High Resolution Infrared Radiometer for nighttime coverage will be added in 1968.

By taking full advantage of the satellite for meteorological observations, many requirements in addition to those agreed upon in the interim operations listed above can be satisfied. This increasing role of satellite meteorology was alluded to in the discussions of the second and third objectives of the program.

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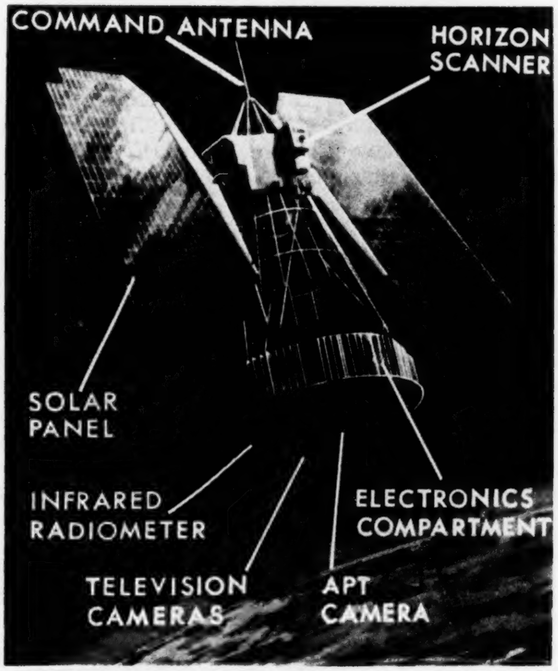
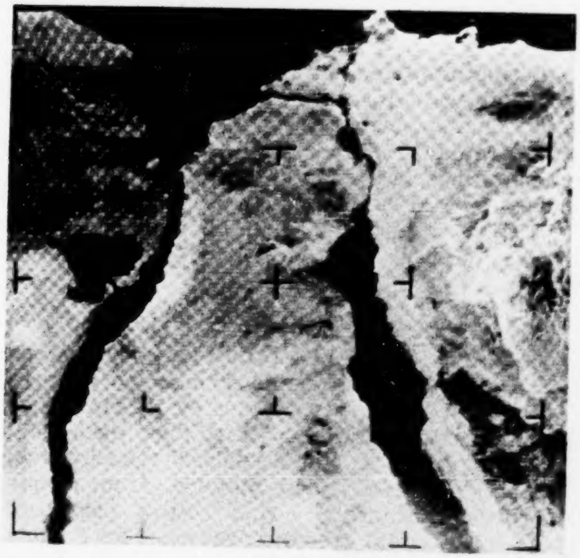
NIMBUS

Certainly such a large undertaking as the National Operational Meteorological Satellite System requires a thorough research and development program for support. This role has been given to the NIMBUS satellite program. Delays and increased costs in the NIMBUS program finally caused a redirection of the National Operational Meteorological Satellite Program in 1963, and the NIMBUS Satellite has become the development tool for testing future techniques and sensors for future programs.

The first of the NIMBUS satellites was placed into orbit 28 August 1964. With NIMBUS I, the National Aeronautics and Space Administration proved beyond expectations that the NIMBUS concept of a research vehicle and storm tracker was valid. During its lifetime NIMBUS I sent back more than 27,000 day and night photographs of weather phenomena around the Earth.

On 23 September 1964, the lubrication in the solar panel drive of NIMBUS I failed and the solar panels locked. Without adequate power to recharge the battery, NIMBUS I ceased to function properly.


COMMAND ANTENNA
HORIZON SCANNER
SOLAR PANEL
INFRARED RADIOMETER
ELECTRONICS COMPARTMENT
TELEVISION CAMERAS
APT CAMERA



The second in the NIMBUS series was launched in May 1966. This satellite included a Medium Resolution Infrared Radiometer (MRIR) system to measure emitted infrared and solar radiation for determining the characteristics of the Earth's atmosphere. It also included a High Resolution Infrared Radiometer (HRIR) which could be readout by using the Automatic Picture Transmission (APT) system at night. The Advanced Vidicon Camera System (AVCS) employed on NIMBUS I was also carried on NIMBUS II and produced many sucessful photographs similiar to the one of the Nile river and Sinai Peninsula in the above photograph. Failure of the tape recorders however, has reduced the transmitted data from NIMBUS II to only the APT camera readouts.

NIMBUS B will carry two SNAP-19 radioisotope thermoelectric generators which will augment the solar cell array for electric power. This system will produce 50 Watts, as compared to 250 Watts from solar cells. It will be flown primarily for experimental test purposes.

In addition to the new generator system, the NIMBUS B spacecraft will again fly the HRIR and MRIR radiometer systems. Experiments will be conducted to collect data on the infared, ultraviolet, and visible spectra of the atmosphere.

The locations of worldwide meteorological platforms and retrieval of meteorological data will be accomplished by the Interrogation, Recording, and Location System. This system will receive information from land and sea-based monitoring stations and relay it to data centers. Such a system could report timely meteorological conditions from areas previously inaccessible.

NIMBUS B, as part of its on-going test program, will employ a camera system capable of continuously providing daylight pictures of Earth's cloud cover. This "continuous motion" camera system will have a real-time readout capability.

Scheduled for 1970, NIMBUS D will carry even more advanced experiments in the visible, ultraviolet, and infrared regions. It will add readout information from constant level balloons to the Interrogation, Recording, and Location system. NIMBUS D will perform additional tasks such as: determining the total amount and vertical distribution of water vapor; determining the total spatial and temperature distribution of ozone in a vertical column; and measuring air temperatures from the ground (or cloudtop) to an altitude of 30 miles with a vertical resolution of 6 miles and a horizontal resolution of about 100 miles.

TOS

The TIROS Operational Satellite (TOS) system (an improvement on TIROS) has been in operation since 15 March 1966 and satisfies General Objective #1 except for the nighttime observation of cloud cover. This system is composed of the spacecraft, ground installations, and the communications linking the ground installations together. Because of its operational status, segments of the TOS system will be described in detail.

Spacecraft of the TOS system are basically descendants of the original TIROS with cameras from the NIMBUS Research and Development program. Improved attitude control has been provided to the spacecraft which is a hatbox-shaped, 18-sided polygon that is 22-inches high and 42-inches in diameter. Solar cells convert solar energy to electrical energy to keep 63 nickel-cadmium batteries charged. Protruding from the top of the spacecraft is an 18-inch receiving antenna. Four 22-inch transmitting antennas extend from the baseplate.

All of the above features and many of the electronics are common to both the Automatic Picture Transmission (APT) spacecraft and the Advanced Vidicon Camera System (AVCS). The AVCS pictures are stored on magnetic recording tape for transmission later to ground stations.

162

With the TOS system in full operation, two spacecraft, one with Automatic Picture Transmission capability and one with picture storage capability, will be in orbit at all times. Once the satellites are in orbit, they are referred to as Environmental Survey Satellites (ESSA). The even numbered ESSA satellites have been direct readout APT satellites, and the odd numbered satellites are picture storage satellites with the AVCS.

In addition to cameras, the AVCS type spacecraft has radiation sensors which are designed to obtain measurements of the global distribution of solar radiation reflected by the Earth and its atmosphere, and of the long-wave radiant energy emitted by the Earth.

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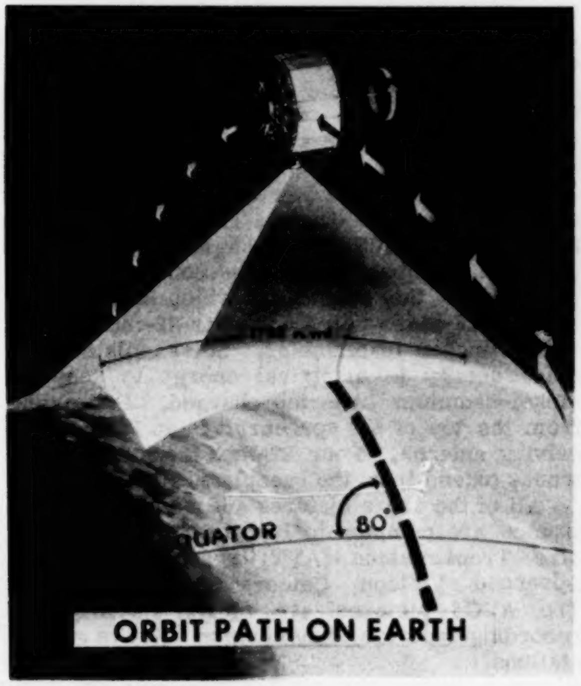
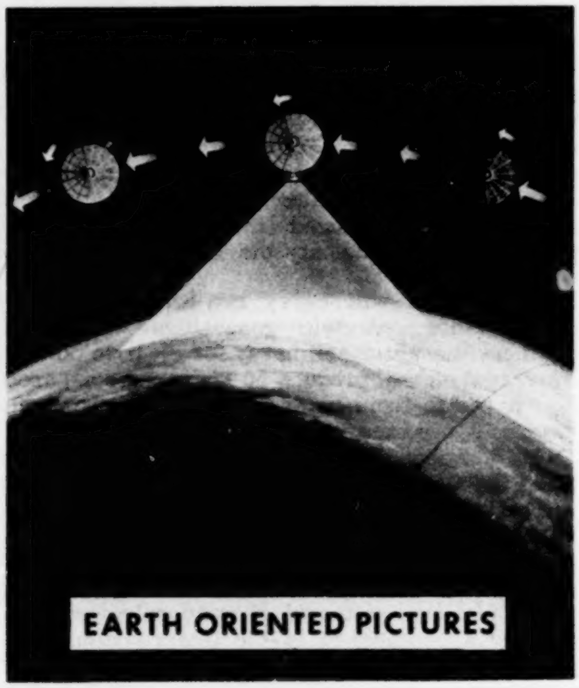
A very important feature of the TOS spacecraft is the ability to control the spin rate and the orientation of the spin axis. This is accomplished by means of large wire coils wrapped inside the spacecraft. When current is sent through a given coil, the magnetic field thus created ineracts with the Earth's magnetic field to give a torquing force. This force can increase or decrease the satellite spin rate or turn the orientation of the spin axis, depending on the coil used. This feature eliminates the need for on-board fuel or gases that many other spacecraft require for stabilization and spin up. After launch, this feature is used to orient the spin axis perpendicular to the plane of the orbit. Essentially, the satellite rolls like a wheel along its orbit. With the cameras mounted perpendicular to the spin axis (looking out the rim), they point directly toward the Earth once each spin. Horizon sensors trigger the shutter at such times, providing Earth-oriented pictures from a spin stabilized spacecraft. This rolling cartwheel type orbit permits greater coverage of the Earth's surface than that of the space-oriented basic TIROS. The initial space-oriented TIROS could look at the Earth only about 20% of the time, while the ESSA satellites of the current TOS system give up to 60% coverage.

Ground installations of the TOS system consist of two Command and Data Acquisition (CDA)



ORBIT PATH ON EARTH



EARTH ORIENTED PICTURES

stations, the National Environmental Satellite Center operations complex, and APT readout stations.

The CDA stations are located at Gilmore Creek, Alaska, and at Wallops Island, Virginia. Each of them has a directional 85 foot diameter antenna and equipment for commanding the spacecraft, receiving beacon, APT and AVCS signals from the spacecraft, and for recording and transmitting those signals. Antenna pointing information and all spacecraft commands are provided to the CDA stations by the operations complex. Because of its geographical location in higher latitudes, the Alaskan CDA can contact a TOS spacecraft daily on each of about two-thirds of its orbits. Because of this extensive contact capability, Gilmore Creek is the primary CDA station and Wallops Island is the secondary.

The National Environmental Satellite Center Operations Complex, Suitland, Maryland, does all of the satellite control computations and data processing functions.

The TOS Operations Center at Suitland provides detailed control of the day-night operation of the CDA stations and the spacecraft. From computer processed information, this center provides antenna look angles, spacecraft commands, and time schedules for spacecraft interrogations. The engineering status of all ground and space equipment is maintained. Spacecraft engineering status telemetry is received and analyzed in realtime. Computations for spacecraft attitude and spin rate changes and subsystems interconnection changes are made and converted to spacecraft commands. The Operation Center controls the TOS ground communications network.

The Data Analysis and Processing facilities at Suitland receive the sensor data from the CDA stations and converts them into usable products - pictures, grids, mosaics, and tape messages. These products are analyzed for meteorological content. Facsimile, teletype messages (coded, and clear text) containing cloud analyses are prepared for wide distribution.

Exclusive communication links are provided for the operation of the TOS system. Wideband links connect the two CDA stations and the operations center complex. These links contain seven 3 khz bands and one 17 khz band. The narrow bands are used for voice, teletype, and telemetry data traffic. The wide center band carries video data. At Offutt Air Force Base, the Air Force Global Weather Central is connected with the TOS communications network and can receive all meteorological satellite data simultaneously with the Operation Center.

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IMPROVED TOS

The Improved TOS will be the third generation spacecraft following TIROS and TOS. This new generation of spacecraft will give direct real-time readouts, as well as stored data readouts of daytime cloud pictures from a single satellite, rather than employ two separate satellites as does the present TOS system using an APT and AVCS satellite. In addition, improved TOS will provide nighttime cloud cover mapping capabilities and have a growth capability to permit easy add-ons of new or improved sensory packages as they become available for operational use.

The first satellite to be launched in the improved TOS series is the TIROS M. It is to be launched into a near-polar, 750 nautical mile orbit by a Delta launch vehicle. It will employ proven system hardware and utilize existing TOS ground station equipment with a minimum of modifications.

SYNCHRONOUS OPERATIONAL METEOROLOGICAL SATELLITE SYSTEM

A Synchronous Operational Meteorological Satellite (SOMS) system will provide fixed continuous observation of the atmosphere from satellites. The current ESSA satellites in near-polar orbits at 750 nautical mile altitude can view specific localities in far polar regions as often as every pass (at 113-minute intervals) but in middle and low latitudes, viewings are restricted to once or twice a day. The synchronous satellite in an equatorial orbit at about 22,300 miles altitude will remain fixed over a position on the equator. Cameras on the synchronous satellite will provide the means for continuously observing the full life cycle of weather disturbances, which can undergo significant changes during periods much shorter than one day. The synchronous satellite, viewing from directly over the equator, is especially well suited for following devastating hurricanes and storms in tropical

164

regions. The satellite can view and track storms up to 52.5° North and South latitudes, which is the maximum reasonable viewing angle for equatorial synchronous satellites.

One possible approach to a SOMS system would use the spin-stabilized satellite already successfully proven in the SYNCOM program.

The primary sensor will be a spin-scan cloud camera which was test flown on the Applications Technology Satellite-I (ATS-I), launched in December 1966. A SOMS system will provide pictures as frequently as every twenty-minutes during daylight hours. Ground resolution of the pictures will be on the order of two to three miles. Provisions will be made either to transmit directly, or store and transmit these pictures in a form compatible with low-cost ground stations similar to the APT stations presently used in conjunction with the ESSA satellites.

A SOMS may also carry communications relay equipment as required to transmit meteorological data between world, regional, and national meteorological data between world, regional, and national meteorological centers. This will include data links with facsimile capability to allow at least a two-way transmission of data between two stations. Any number of additional stations can listen simultaneously with simple inexpensive ground equipment. Additional capability may also be incorporated to permit collection of data from automatic meteorological stations in remote areas or from balloons and buoys.

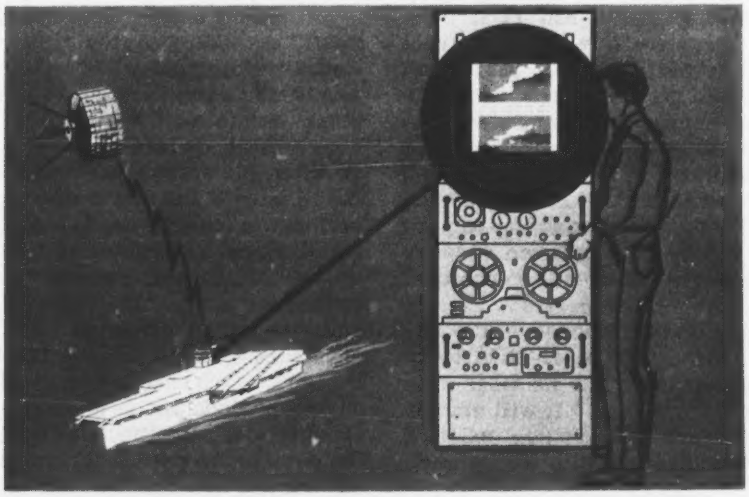
Two synchronous satellites on the equator with one placed at 50° West and the other at 150° West longitude would permit observation of the Atlantic and Pacific Ocean basins and a major portion of the Americas. They would be controlled from a single Command and Data Acquisition station located in the south central United States. In addition, the deployment of SOMS at these longitudes would permit meteorological data transfer between two world centers (Washington and Melbourne), six or seven regional centers, and up to about 55 national centers.

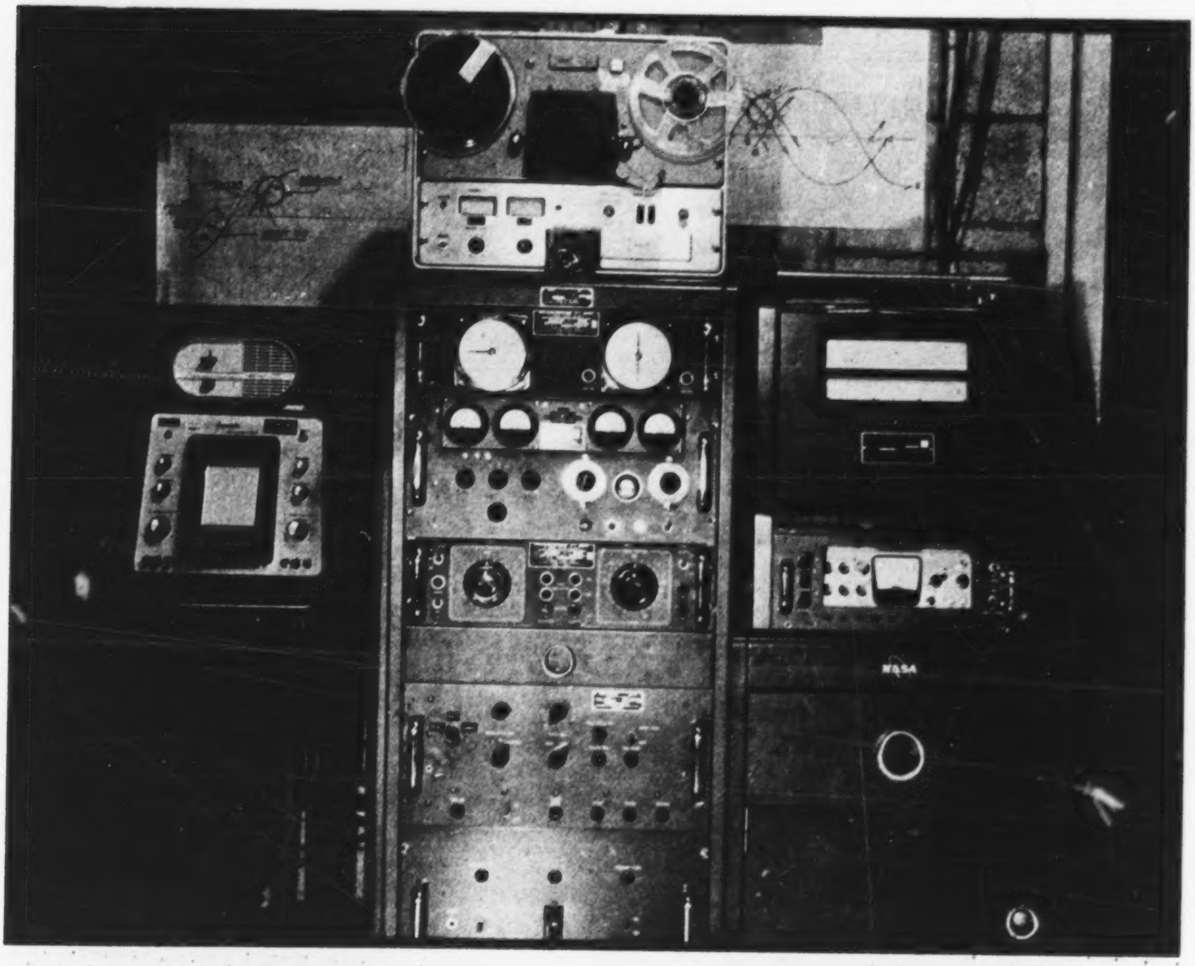
Further study and development may result in a slightly different approach in some respects than that discussed here for SOMS.

NAVAL APPLICATIONS

By now, it is apparent that our nation intends to use the unique capabilities of satellites for meteorological purposes. It should also be apparent to the seagoing sailor that their use can be an asset to him.

Naval Fleet Commanders have always been plagued with inadequate weather reconnaissance support. This scarcity of data has been partially due to insufficient observation stations and partially to difficulties in collecting, analyzing, and forwarding the information to interested areas. The Navy has attempted to alleviate this problem by numerous means of improved technology. The meteorological satellite is proving itself to be a solution to many of the problems that face the fleet commander. Information concerning weather phenomena in remote areas is much more readily available now than it has been at any time in the past.





The standard Automatic Picture Transmission system readout equipment, shown in the accompanying illustration, has been modified and repackaged for use aboard Navy ships by the Naval Electronics Laboratory, San Diego, California. The system which will be operating on new aircraft carriers by the end of 1967, is referred to as the AN/SMQ-6 Shipboard Meteorological Satellite Readout Station. As installed aboard Navy ships the system includes the antenna, receiver, magnetic tape recorder, facsimile recorder, demodulator, and the associated controls for these components.

This fleet-compatible system receives the ESSA satellite signals in a real time programmed basis consistent with the orbital track information. The satellite-borne equipment consists of a controlled shutter, a 1-inch diameter storage vidicon with 800-line TV resolution, vidicon electronics, video circuitry, modulator, and 137.5 megahertz, 5 Watt FM transmitter. The storage vidicon permits a nominal 200-second frame scan time. At a 750 mile altitude, each picture covers 1700 by 1700 NM, with a 30% overlap. The time required for the camera to take the picture and to readout completely is 208 seconds.

The APT readout station consists of three basic components: antenna, equipment console, and display recorder. Various types of antennae have been utilized, such as an 8-turn helix, a flat dish and a cone. The equipment console includes the FM receiver, which is equipped with both aural and visual means of determining the presence and condition of input signals, and a tape recorder. The display/recorder forms an 800-line picture using ten shades of gray varying from black to white.

Naval operations are influenced greatly by the weather. A reliable satellite system which will provide real-time readout of cloud cover will greatly enhance the decision making of commanders afloat and in the field. With such a system, day-to-day operations as air strikes, in-flight refueling, replenishment at sea, and ASW operations can be planned and carried out with weather as a friend, not as a foe.

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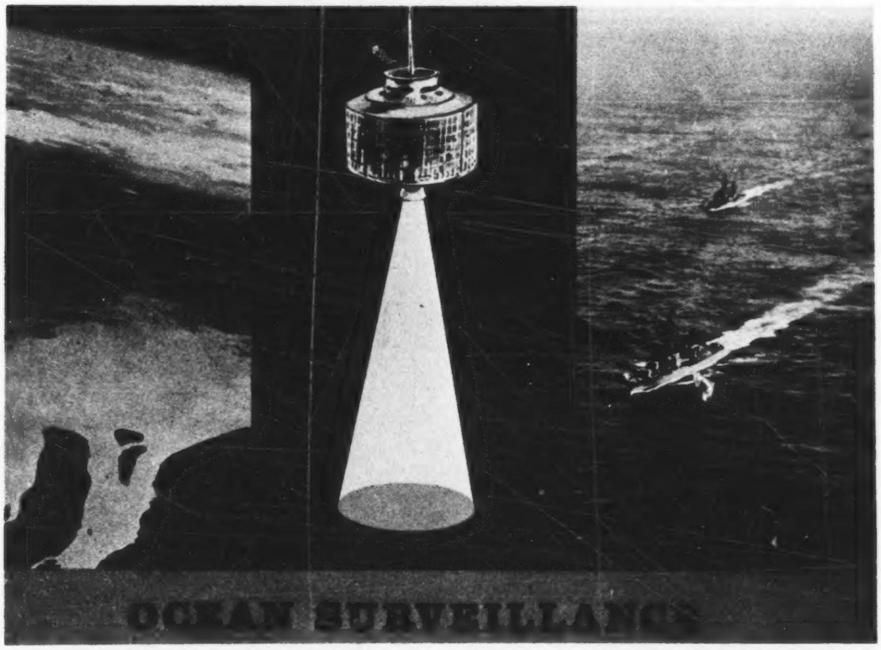

Operational Aspects

The accomplishments of meterological satellites indicate other possible applications of observation platforms operating in the environment of space. Deployment of near-Earth satellites for maintaining Earth surveillance represents a new and important consideration for any nation seeking to prevent surprise attack in military maneuvers. Indeed, the military advantages that accrue from proper reconnaissance and surveillance are interwoven throughout the history of warfare.

From the time man first began fighting for control of the seas, ocean reconnaissance and surveillance have been major problems. The questions . . . What's out there? . . . Where is it? . . . and . . . What is it doing? . . . have caused naval commanders many sleepless nights. Finding answers to these questions in an active situation imposes an extremely difficult task on available operational forces which, ideally, should be free for offensive action.

The Navy's ability for effective offensive and defensive actions can be tremendously influenced by data supplied from orbiting surveillance satellites. Such data pertaining to enemy ship movements, as obtained by satellites scanning the oceans of the world, could assist a fleet commander in the strategic and tactical placement of forces and in the planning of offensive strikes. At-sea operations could be conducted while simultaneously monitoring enemy activity both on land and at sea. Such knowledge of impending enemy operations would provide the tactical commander with significant information upon which to make intelligent battle decisions.

However, the reverse side of the coin is just as important to our Navy. The employment of satellite observation technology by an enemy could force naval commanders to adjust their military tactics to meet the challenge of an informed opposition. Such an enemy might monitor our naval operations thus reducing the effectiveness of any fleet maneuver. Normal fleet activity would then be under close enemy scrutiny. Action could not be conducted without the distinct probability that the enemy was aware of certain operations. Any naval forces planning to perform exercises under these circumstances would be well advised to adjust tactics and defenses for this impact of space technology. Naval commanders must, therefore, be prepared to carry out their assignments as well as to protect their crews while maneuvering within enemy visibility.

Technological Aspects

The operational aspects of Earth surveillance systems are not the only areas that deserve attention in this brief discussion of observation platforms. Consideration must also be given to the development of special sensors which are necessary for satellite observation systems. An electro-optical television sensor, or even a photographic sensor, similar to those discussed for meteorological satellites, may be adapted for observation of objects other than cloud cover. However, limitations inherent in all optical sensors reduce their effectiveness for military surveillance. Clouds and darkness preclude full-time coverage by such optical sensors. Therefore, other sensors must be developed if total world coverage at all times is a desired goal.

In order to provide such coverage by continuous all-weather surveillance, sensors are being developed which operate on principles of radar and infra-red radiation. The progress obtained from continuing technological research will determine the advantages of each sensor type. Indeed, a future observation platform might consist of several sensor units, each of which supplies information to assist fleet commanders in evaluating a special situation.

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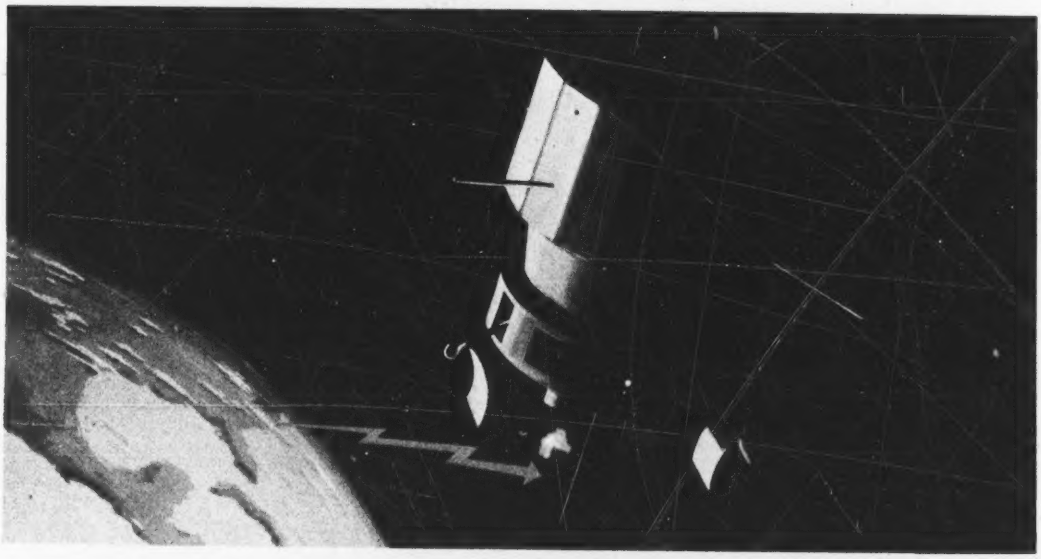

Present Status

At this point we must recognize that other ground-supported surveillance systems presently exist. The satellite method discussed here represents only one aspect of the overall integrated surveillance program. Satellite inputs could be integrated with other existing sensor networks to provide complete tactical information to fleet personnel. Such a complete ocean surveillance network will also employ sensors uniquely suit-

168

ed for reporting of ocean contacts. Today, space technology may well provide fleet commanders with a new method for conducting more effective naval operations. This use of space should present the naval commanders with considerable impetus to contemplate new naval strategy. Enemy use of space technology in surveillance will force radical changes in traditional warfare techniques. Our Navy is aware of this ramification and is pursuing, through technical and operational studies, a systematic approach for an answer to the ''Spy in the Sky'

CHAPTER 15

MEASUREMENTS FROM SPACE

GEODETIC SATELLITES

General

Geodesy is the science concerned with determining the size and shape of the Earth. It includes not only the mapping of the relative positions of land objects but also their variations in terrestrial gravity. Mapping has been a problem of practical interest from the time man first traveled from one place to another, or felt the need to describe boundaries exactly. Such problems have usually been solved through mapping by surveying methods.

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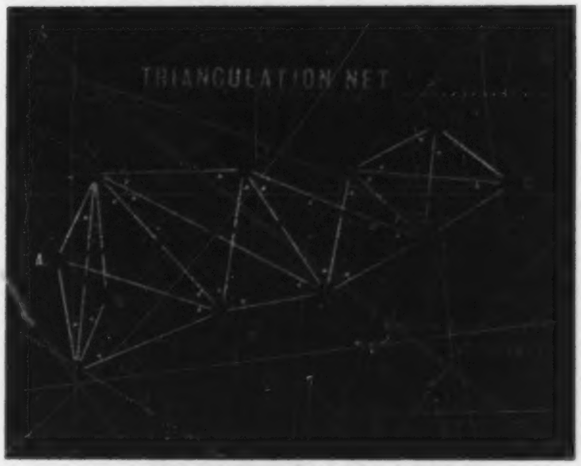
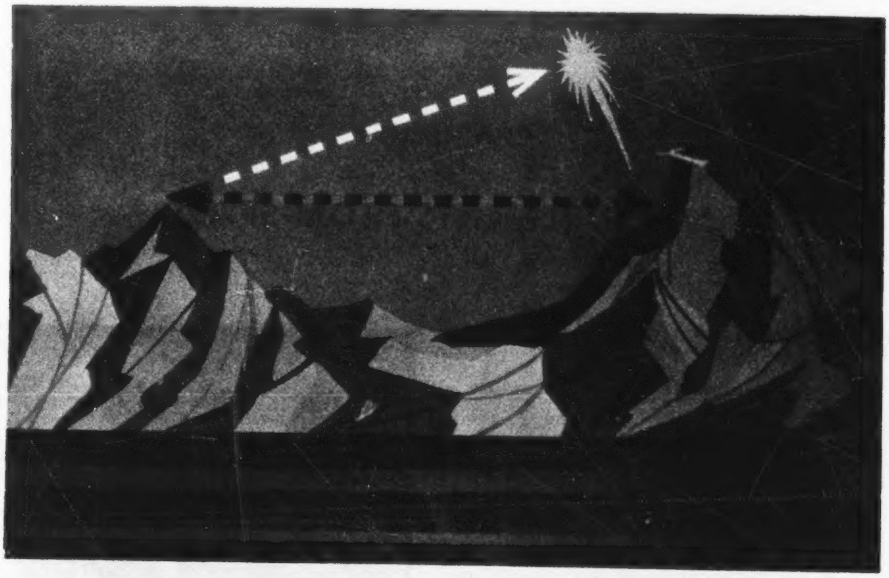


The earliest methods of surveying provided the users with only the barest information, such as "y is two days walk from x." Mapping methods have evolved principally by improvements in the technique of surveying known as triangulation and trilateration. The accuracy in such techniques is limited only by the accuracy of the measuring devices used, and the detailed knowledge of the surface plane or arc (the datum) to which the measurements are referred.

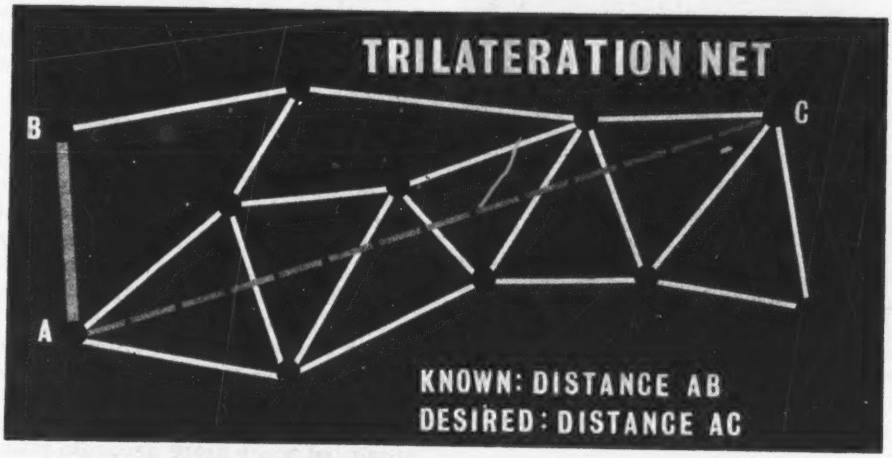
Triangulation is the most widely used technique for surveying areas. This method consists of establishing a straight line base between two points, then accurately observing a third distant point from each of the end points of the base line. By measuring the observation angles formed, enough information is obtained to calculate the length of the other two sides of the triangle. For more precise measurement of distances, instruments are placed at all three points of a triangle covering the survey area. This is a more difficult but much more accurate process.



Flare Triangulation is a technique for surveying when obstacles or distances preclude direct observation of the third point of the triangle. In order to survey such an area, usually 2 distinct reference objects (flares or other elevated objects) are observed simultaneously from three or more separated points. By measurement of both elevation angle and the azimuth direction angle at each observation point, the separation distances between the observation points can be calculated.

Recently, long range radar has been used to obtain accurate measurements of distances between radar stations. In the process of Trilateration, the lengths of all sides of a triangle are measured repeatedly and very accurately. Lines as long as 500 miles can be measured relatively quickly, and surveys can be extended over vast areas in a short period of time.

Through such accurate surveying and mapping, man's understanding of the size and shape of his environment has changed from the "flat"-Earth concept predominant before the sixteenth century, to our present knowledge that Earth is spheroidal with small but significant irregularities.

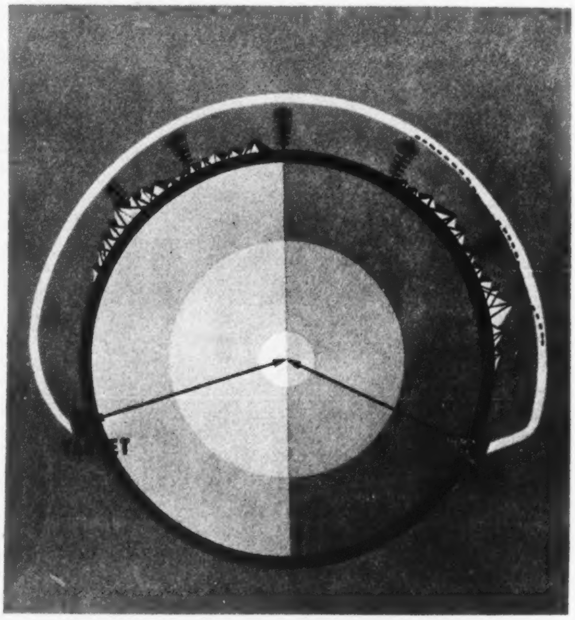


Today, the major portions of the United States have been surveyed and mapped to a high degree of accuracy. The breadth of the country is straddled by triangulation nets which have been measured several times to an accuracy of approximately 50 feet.

In addition to this network, a reference point for relating measurements has also been established. This reference is called the North American Datum. This datum is the reference used within the Americas to map adjacent ocean areas and measure distances to other continents. Although the accuracy of these intercontinental ties is adequate for most navigational purposes, overall accuracy is relatively poor when compared to land triangulation nets.

Other countries have surveyed and mapped their lands to satisfy their national needs. It might appear therefore that all which would be necessary for a complete and accurate model of the world would be to join the many national surveys by intercontinental ties. Minor errors in these ties might then be reconciled through our astronomical knowledge of the Earth.

Regretfully, this is not the case. National surveys use different datums, or reference arcs, chosen by convenience to represent only that section of the Earth upon which the survey is made. If the Earth were a true sphere, these reference arcs would match perfectly and geometric integration of national surveys would pose no problem. However, because our Earth is not a perfect sphere, each reference arc is of different curvature; for example, the Earth based upon the Tokyo Datum is quite a different shape than that upon the North American Datum.



Reconciliation of these datum arcs to a single reference point is a complex problem with many military implications. For example, the ballistic missile is a weapon capable of spanning the distance between the major land masses of the earth in a very few minutes. However, beneath its lofty trajectory, the Earth still presents many geodetic problems which, if left unsolved, will diminish the effectiveness of the weapons and of mobile launch systems.

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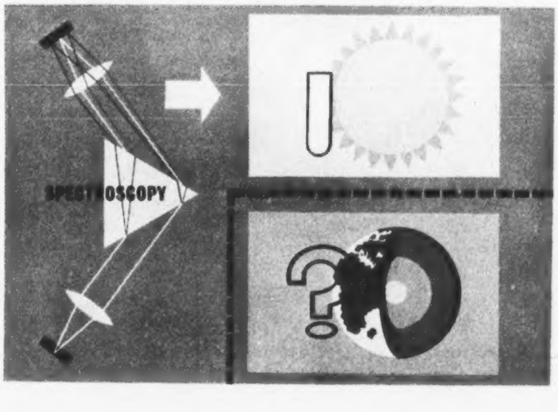
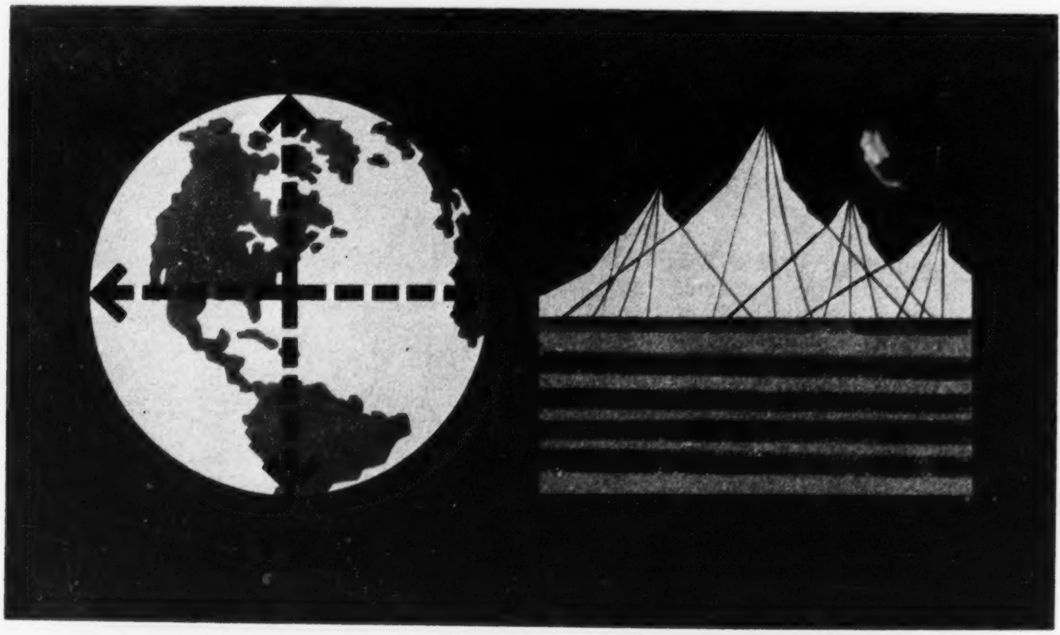


These problems exist today because less is known about the Earth, in some respects, than is known about many of the celestial bodies. For example, through the science of spectroscopy, astrophysicists can give an excellent description of the chemical composition of the sun; by contrast, little is known about the internal constitution of the Earth. Let us consider some problems affecting a ballistic missile racing toward a distant target. The problems presented to Earth are of two kinds: geometrical and geophysical.



Geometrical

This area of geodesy concerns the size and shape of the earth, the accuracy of intercontinental survey ties between the land masses of Earth, and the position of the launch site and the target with respect to the survey datum of the land mass upon which each is located.

Determinations of the size and shape of the Earth have been research problems for man throughout the centuries. Until recently, however, geodesists have been seriously hampered by the tools with which they have had to work. Today, satellites are used as scientific tools to fill many voids in our knowledge of the Earth. They provide information to help determine survey ties between the several land masses of the Earth and the positions of many remote islands, which have been recently subject to errors varying from a few hundred feet to several thousand feet.

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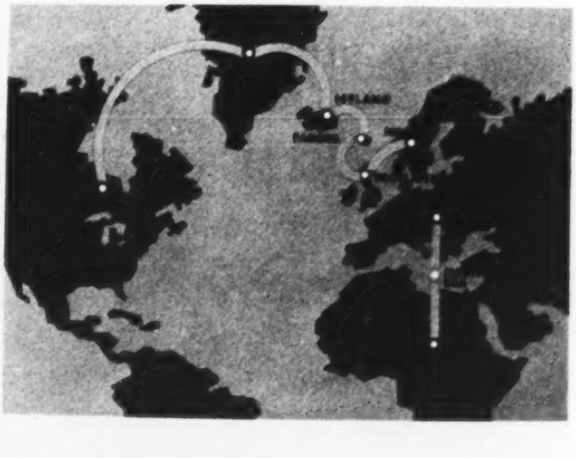
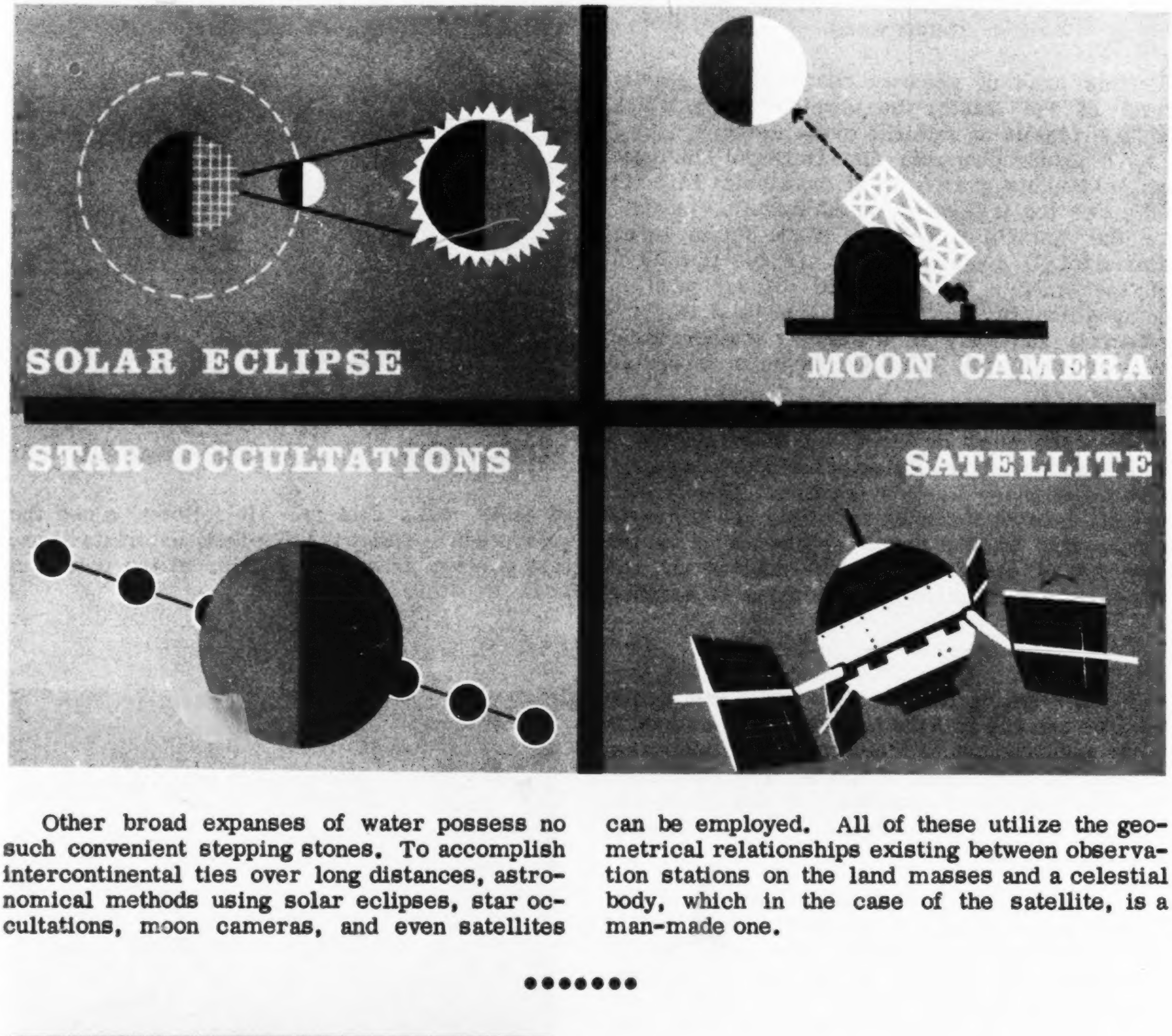
Intercontinental survey ties are made by a variety of methods including optical, electronic, and celestial techniques. The optical method is limited to line-of-sight ranges between two land masses, or observation of a common object, such as a flare, from points on two separated land masses. This technique has been used for performing the ties between England and the Continent. Electronic devices such as SHORAN (Short Range Navigation) and HIRAN (High Precision SHORAN) have accomplished ties across the Mediterranean Sea between Africa and Europe and, by leapfrogging from Norway to Scotland to the Faroes to Iceland to Greenland and thence to Canada, have completed the tie between Europe and North America.





Other broad expanses of water possess no such convenient stepping stones. To accomplish intercontinental ties over long distances, astronomical methods using solar eclipses, star occultations, moon cameras, and even satellites can be employed. All of these utilize the geometrical relationships existing between observation stations on the land masses and a celestial body, which in the case of the satellite, is a man-made one.

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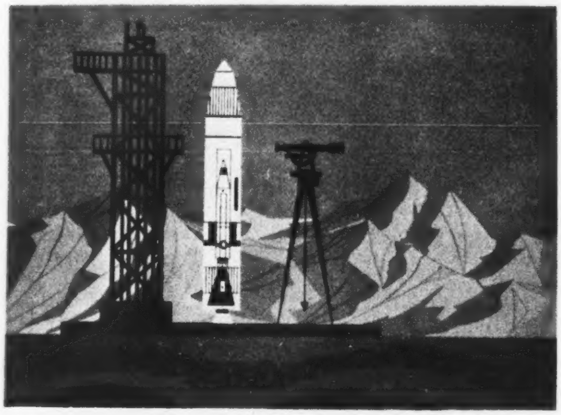


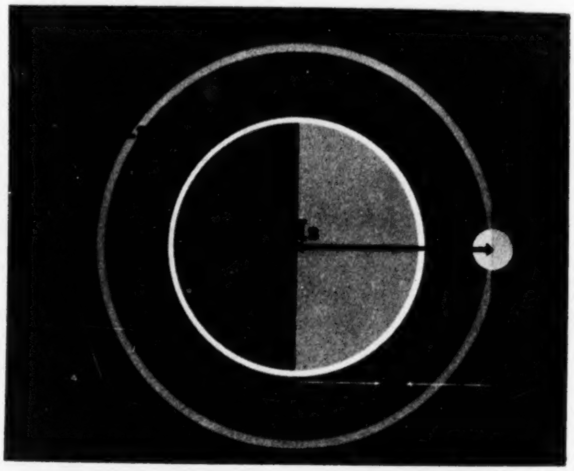
Finally, from the ballistic missile standpoint, the horizontal and vertical position of the launch pad must be known with respect to the survey datum of the land mass upon which it is located. Of course, similar position information is required for the target. Target information is more difficult to obtain since the target is seldom located in friendly territory! Intelligence sources, rather than survey parties must furnish such information.

Geophysical

This area of geodesy concerns the gravity field of the Earth, the physical force which links a missile or satellite to the Earth.

All changes in the direction and intensity of the Earth's gravity field from point to point influence the trajectory of the missile. Gravity on the Earth's surface is made up of three elements: (1) mass attraction, (2) inertial effect of the Earth's rotation, and (3) variation in composition of the Earth. The first two are classical and vary in a regular mathematical manner while the third varies in an irregular manner.

The first of these elements is the attraction between the mass of the Earth and a mass situated on its surface. Let us assume for a moment that we stop the Earth's rotation. Gravity then merely follows Newton's universal law of gravitation, that is, the force of attraction varies directly as the product of the masses and inversely as the square of the separation distance of their mass centers. It follows, since the polar radius is shorter than the equatorial radius, that surface gravity is greater at the pole than at the equator.



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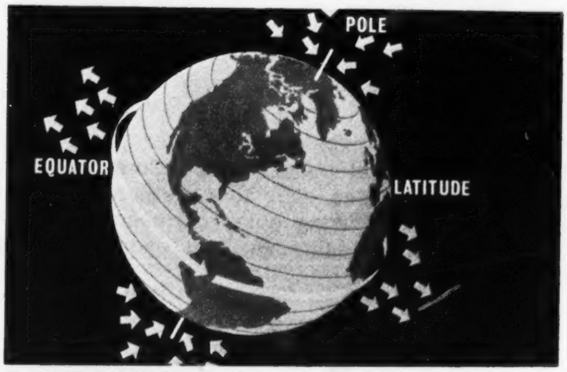
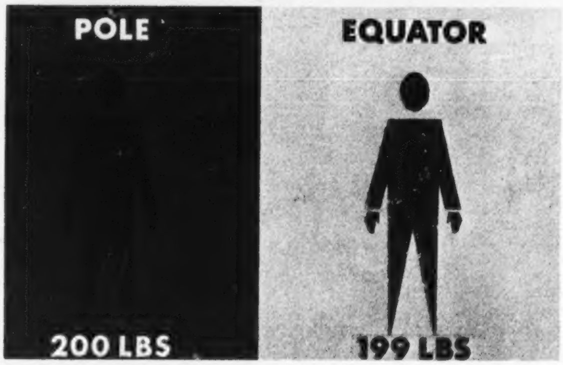
Next, allowing the Earth to spin again on its axis, we can see that the inertial effect on objects at the surface due to the Earth's rotation gives an outward component of acceleration perpendicular to the axis of rotation. In this respect it may be said that the inertial effect of rotation is anti-gravity.

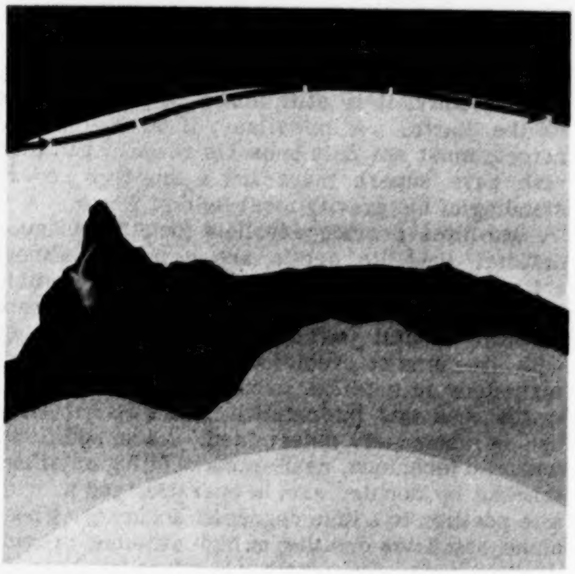
The greatest centrifugal effect is at the equator because this is the position of greatest rotational velocity. There is no effect at the pole since the pole is on the axis of rotation. Between the equator and the pole, inertial effects vary in a regular mathematical manner. This is to say that the inertial effect anywhere on the Earth's surface varies as a function of the latitude. Considering these two regular variations of gravity, there is a difference of one part in 200 between pole and equator. A man weighing 200 pounds at the pole would weigh 199 pounds if transported to the equator.

There is, however, a third disturbing factor which complicates the problem. The Earth is not homogeneous; its mass is not uniformly or evenly distributed. Its crust is thick in places and thin in others. The thickness varies between about 3.7 and 37 miles, with an average of about 22 miles. One explanation for the variation in crustal thickness is the "roots-of-the-mountains theory"... the theory of isostacy.





This theory of isostacy postulates that the crust floats in a sea of dense magma which is probably in a plastic state. Icebergs floating in the sea provide an excellent analogy. From experience one knows if an iceberg has a large mass above the waterline, it must have a much larger mass below the waterline to provide sufficient buoyancy. So it might be with the Earth's crust. A large mountain mass will sink deeply into the magma until it finds enough buoyancy to support itself. This depression into the magma is called a mountain root. A smaller mountain will have a smaller root. An ocean basin or ocean trench will produce what is known as an anti-root. Using this model, consider the flight path of a ballistic missile or a low orbit satellite. During a flight the vehicle will experience variations in gravity due to various land masses which differ in density. These may range from water to granite, which is 2 1/2 times as dense as water, or to mountain ores about three times as dense. At every point in the path the vehicle is subjected to gravity of varying intensity.



Furthermore we must not only consider a change in gravity intensity but also a change in the direction of the local gravity vector. If a mass were suspended in the vicinity of a large mountain, it would be deflected toward the mountain away from the vertical. This change would be due to the proximity and high density of the mountain on one side and the presence of lower density water on the other. The maximum amount of this deflection at the Earth's surface is about eighty-five seconds of arc. This is not always negligible. For flights of 5,000 miles range these variations can introduce a built-in error of a mile or more even if the precise locations of launch site and the target are known.

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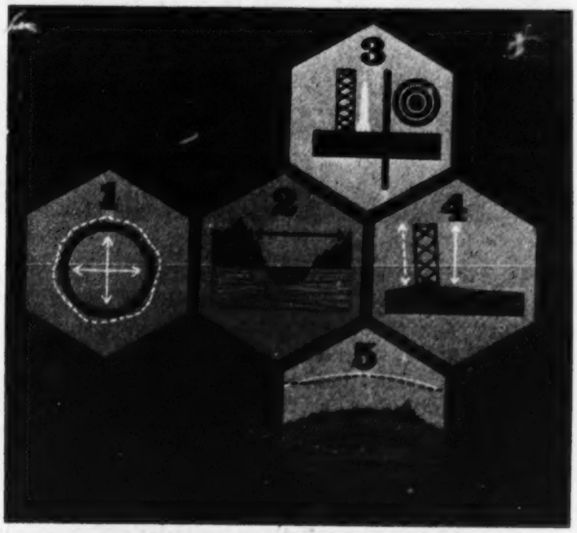
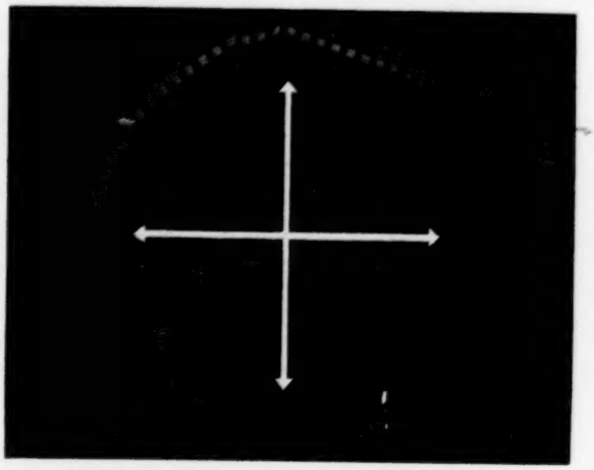


Let us summarize the problems, both geometrical and geophysical, of a ballistic missile. Basically, the size and shape of the Earth must be known. Then ralative positions of the two land masses containing the launch site and the target must be known. Additionally, the specific locations of launch site and target must be identified with respect to the land mass upon which each is located. Furthermore, any deflection of the local vertical at the launch pad must be known so that the inertial guidance system can be oriented with respect to the true vertical and not to the local vertical. And finally, throughout the entire flight, from pad to impact, the varying intensity and direction of gravity must be known for the altitude of the missile.

Although a missile at apogee is hundreds of miles above the surface, and shows in a telescope only as a bright speck traveling at very high velocity, it is still linked by physical laws to the Earth. A missileer, if he is to hit his target, must not only know his weapon, but must also have superb maps and a thorough understanding of the gravitational field of Earth.

Satellites provide excellent tools to aid geodesists. Satellite orbits are governed almost entirely by the distribution of masses within the Earth. Modern tracking methods permit satellite orbital parameters to be determined with the utmost precision. By observing perturbations in satellite orbits and working backwards with this information, mass distributions can be accurately determined. As an additional geodetic technique, near-earth orbiting satellites tracked by doppler are in operation and provide site position to a high degree of accuracy. These same satellites orbiting at high altitudes provide orbiting reference points which can be observed simultaneously from widely separated points on the Earth's surface. With satellite aid, triangulation and ranging observations and modern data processing techniques permit precise location of points in remote areas to a degree never before attainable.



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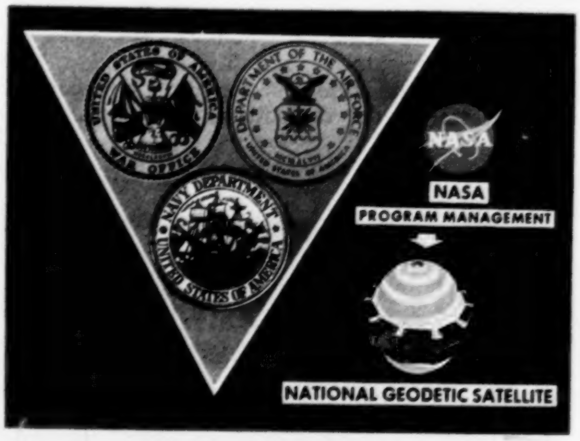
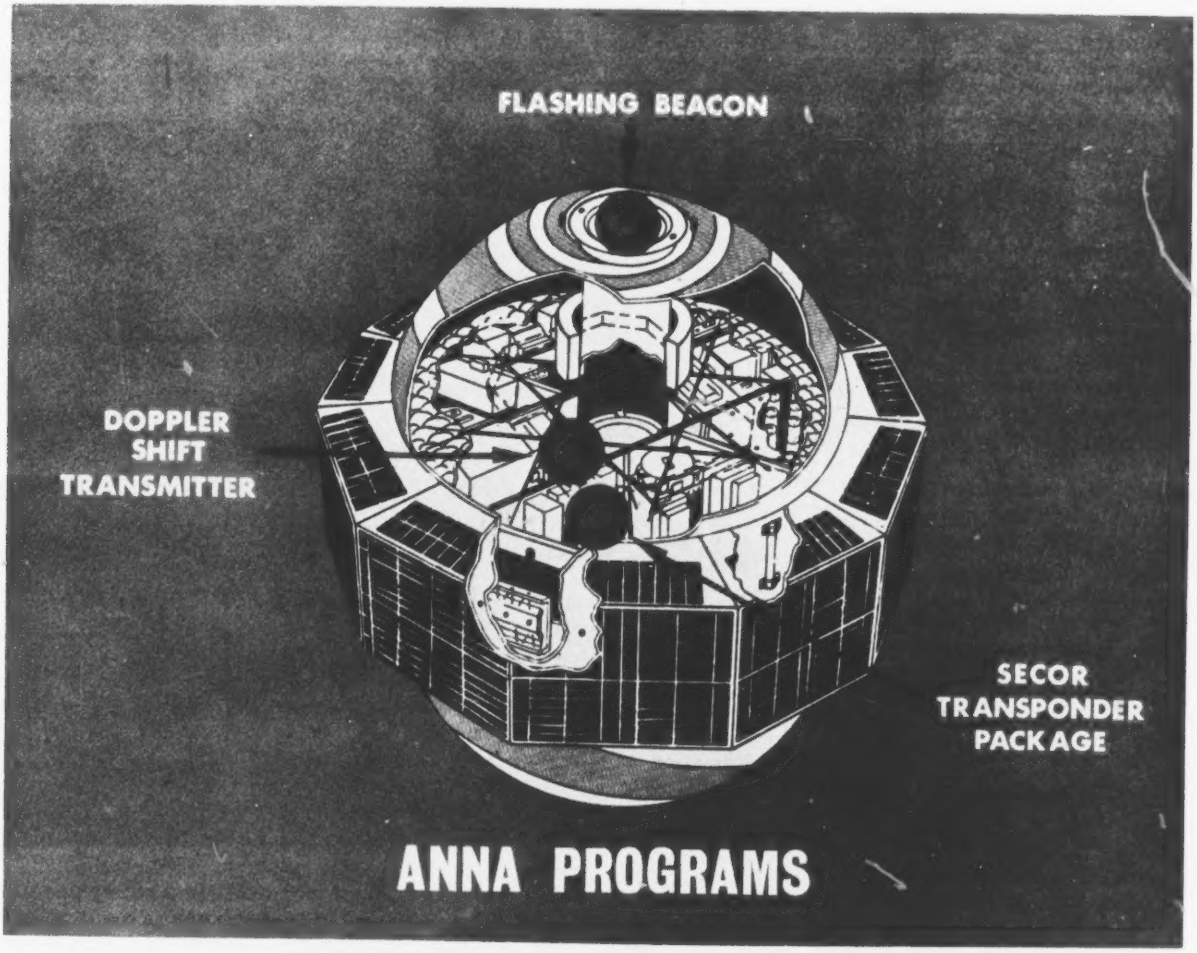
Program Status (June 1967)

Recognizing the critical importance of geodetic problems to the military services, the Army, Navy and Air Force are conducting a tri-service geodetic satellite program under the sponsorship of the Defense Intelligence Agency. The Navy Satellite Geophysics Project, sponsored by the Oceanographer of the Navy, supports the Defense Intelligence Agency's requirements for mapping, charting and geodesy and also supports the National Geodetic Satellite Program managed by NASA. The original geodetic satellite program was called ANNA, an acronym for the sponsors—Army, Navy, NASA, and Air Force. This program was under the management of the Navy until 1963 when the responsibility for a National Geodetic Satellite Program was assigned to NASA.

The original program called for a series of five satellite launches into orbits varying from circular to highly elliptical and at different inclinations. The first satellite to be successfully orbited was the ANNA-1B which was placed in a 600-mile circular orbit with a 50° inclination on 31 October 1962. Because of its relative success and expected program changes, further flights of this type were not conducted. ANNA 1B was a test bed vehicle designed to provide comparison of three different measurement systems for making high precision geodetic measurements. The three systems were (1) optical, (2) doppler shift of radio signals, and (3) radio ranging. The basic equipment on board the satellite included a flashing beacon provided by the Air Force, a SECOR transponder provided by the Army, and a doppler type transmitter provided by the Navy. The flashing beacon used two sets of Xenon flash tubes designed to produce a series of five light flashes several times a day.

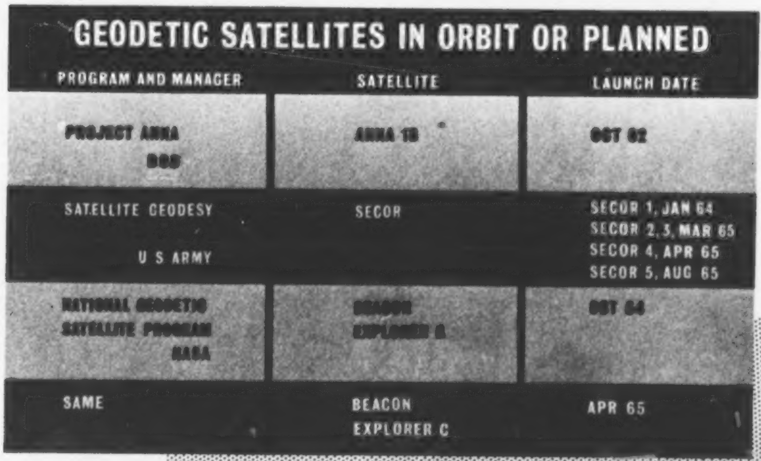




The light flashes were photographed against a background of stars with Schmidt and PC-1000 telescopic cameras for triangulation purposes. The SECOR transponder (SECOR stands for sequential collation of range) was designed for interrogation on six or seven passes a day to provide very accurate ranging for trilateration. The Navy's doppler equipment was essentially the standard package carried aboard its navigation satellites.

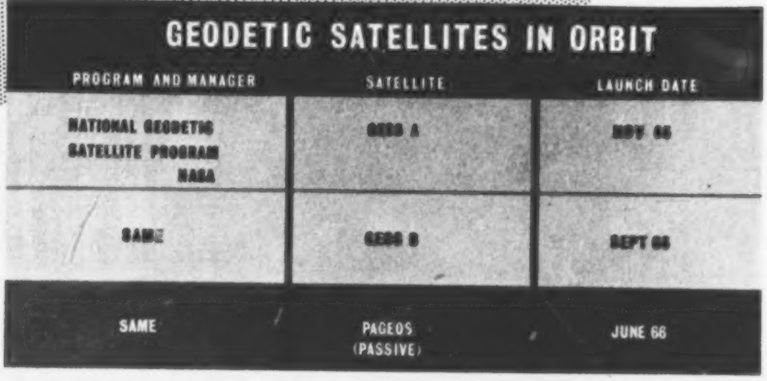
The ANNA 1B satellite encountered power supply problems almost immediately, so that its systems were only partially effective. Nonetheless, ANNA 1B had a useful life time of well over a year. During this time tracking stations at fifty-seven different locations made geodetic measurements. Despite its shortcomings, this test bed satellite provided a great deal of information. It is reported that ANNA 1B, along with the Navy's Navigation satellites, provided eighty percent of the geodetic information necessary for the Navy's successful navigation satellites.

In addition to the power supply difficulties of ANNA 1B, direct comparison of the different measurement techniques proved extremely difficult because there was no long base reference line on the Earth's surface surveyed to the necessary precision. This has subsequently been remedied by a special Coast and Geodetic Survey. A thousand-kilometer range in the Southeastern United States has been surveyed to an accuracy of one part in a million. Only with such a calibrated range can various measurement techniques be rigorously compared for accuracy.



GEODETIC SATELLITES IN ORBIT OR PLANNED

PROGRAM AND MANAGER	SATELLITE	LAUNCH DATE
PROJECT ANNA DOD	ANNA 1B	OCT 62
SATELLITE GEODESY U S ARMY	SECOR	SECOR 1, JAN 64 SECOR 2, 3, MAR 65 SECOR 4, APR 65 SECOR 5, AUG 65
NATIONAL GEODETIC SATELLITE PROGRAM NASA	BEACON EXPLORER B	OCT 64
SAME	BEACON EXPLORER C	APR 65



GEODETIC SATELLITES IN ORBIT

PROGRAM AND MANAGER	SATELLITE	LAUNCH DATE
NATIONAL GEODETIC SATELLITE PROGRAM NASA	GEOS A	NOV 65
SAME	GEOS B	SEPT 66
SAME	PAGEOS (PASSIVE)	JUNE 66

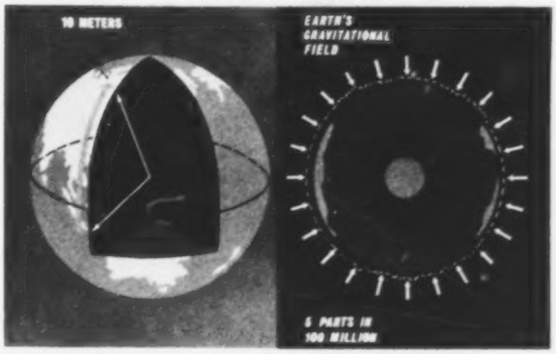
Any satellite which can be tracked can be used in the Geodetic program. For example, the United States has received useful geodetic information from examining the orbits of the Vanguard and Syncom Satellites, which were not primarily intended for geodetic use.

Additionally, navigation satellites have been employed for geodetic purposes. The Naval Weapons Laboratory has reported refinement of the location of fourteen remote islands in the South Pacific to an accuracy of 25 meters, using ANNA 1B and several of the navigation satellites. Of an additional one-hundred sites positioned by the Naval Weapons Laboratory, thirty-four have been positioned to an accuracy of 15 meters.

A listing of Geodetic Satellites now in orbit and the status of the program is shown in the accompanying figure. One should note that (1) SECOR is primarily used for the Army Map Service, and (2) The Beacon Explorer satellites, launched in October of 1964 and April of 1965, carry the familiar doppler equipment. In addition the Beacon Explorer satellites carry special reflectors designed to test the use of laser beams for tracking and ranging.

On November 6, 1965 the first in a series of heavily instrumented GEOS satellites was orbited. These satellites will again compare different measurement techniques—this time against a precisely calibrated baseline. The GEOS satellites carry powerful flashing lights and a variety of electronic beacons; namely, a doppler transmitter, a SECOR transponder, laser reflectors, and when conditions permit, radar reflectors and radar beacons. GEOS B is to be launched early in 1968.

On June 24, 1966 a large reflective balloon type satellite was placed at an altitude of 2300 miles in a circular polar orbit. This is the PAGEOS (passive geodetic Earth orbiting satellite). It provides a reflecting light source which scientists hope to use over the next five years to determine the precise location of land masses and their relationship to each other.



At this time the world is girded by an integrated network of over forty tracking stations, some 2,500 to 2,800 miles apart. These stations are using triangulation methods, including doppler methods, to position all points on the Earth. Special measurements are also made worldwide to improve our understanding of the Earth's gravitational field.

The major immediate goals of the Geodetic Satellite Program are, as a minimum, the location of all major geodetic systems in common geocentric coordinates to an accuracy of 10 meters, and a description of the structure of the Earth's gravitational field to an accuracy of five parts in one hundred million.

The Department of Defense is participating with NASA in the National Geodetic Satellite Program as a follow-on to the ANNA program. It is of immense importance to the Defense Department and the scientific community of the world.

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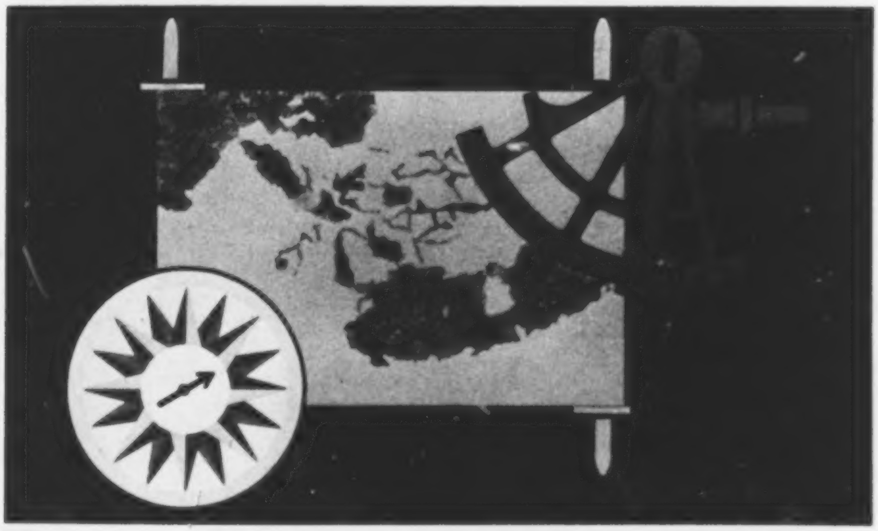


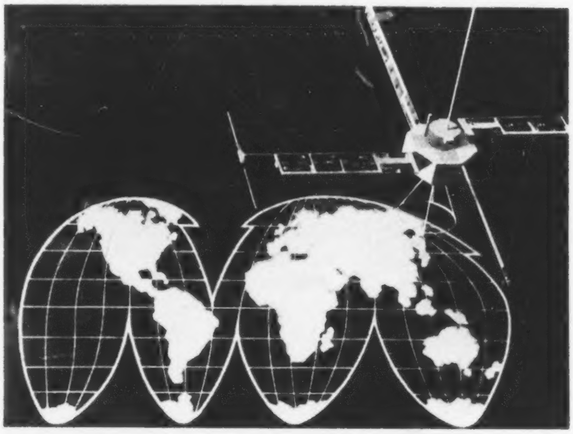
NAVIGATION SATELLITES

General

Navigation is essentially the science of steering ships or aircraft from place to place. This rather brief description might be expanded by saying that, in general, navigation consists of defining the route, guiding a craft along that route, and checking its position from time to time to determine progress.

The state-of-the-art of navigation has developed slowly throughout history. It is interesting to note that maps go back to the Alexandrian Greeks, but it was not until the advent of the magnetic compass around 1180, that the construction of an accurate sea chart became possible. Gradually, navigation has been improved by the use of nautical almanacs for locating stars, with better instruments such as the sextant, and accurate timing devices known as marine chronometers. Yet, sailors of just yesterday would certainly be impressed with today's navigational accuracy obtained by new electronic systems based upon novel uses of basic principles.

Today, one such new system—the Navy's Navigation Satellite System, is providing highly accurate position locations to specially equipped ships anywhere in the world, day or night, in any kind of weather.



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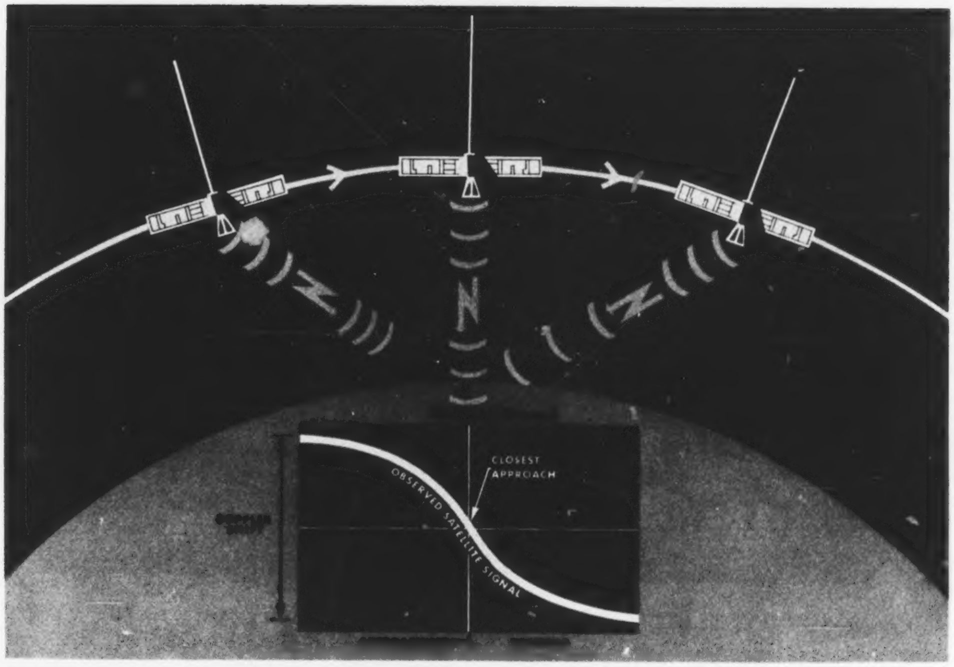
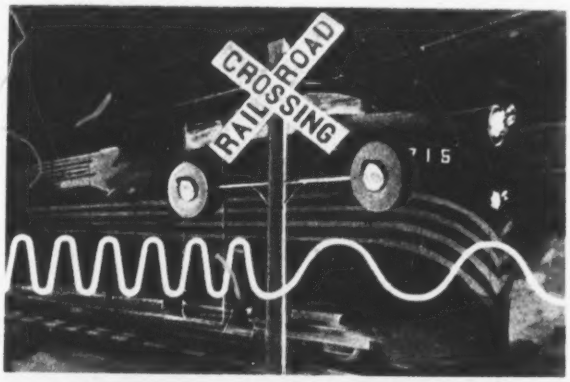


Doppler Principle

The Navy's Navigation Satellite System is based upon a well-known phenomenon of wave motion, the Doppler principle. A wave signal transmitted by a source which is undergoing motion relative to a receiver will be received with a "Doppler Shift" in frequency as a result of this relative motion. Specifically, as a satellite transmitting a constant radio signal approaches, the received frequency will be higher than the transmitted frequency but it will decrease rapidly as it passes through the closest point of approach, where (because instantaneously there is zero relative motion) the received frequency will be the same as the transmitted frequency. As the satellite recedes from the observer, the received signal continues to decrease in frequency to below the transmitted frequency (a negative Doppler Shift).

An anologous situation is the change in pitch of a whistle from a passing locomotive as received by a stationary bystander. This phenomenon is due to a compression and expansion of wavelengths caused by the relative velocity of the passing transmitter. The exact amount of this Doppler Shift in frequency depends on the relative motion of the transmitter with respect to the receiver.



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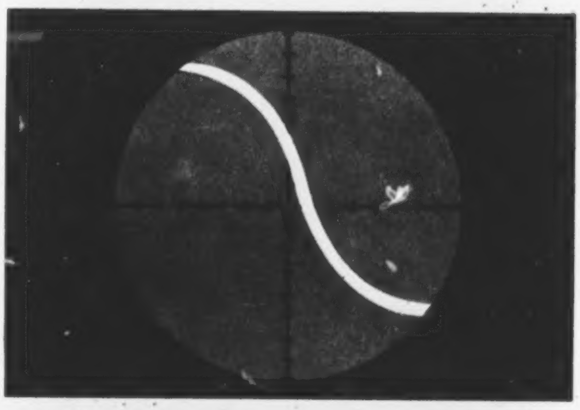
This Doppler effect is measured by counting received cycles for precise time intervals. The received frequencies can be computed and plotted as a descending curve versus time. The shape of the curve depends on the relative motion between the transmitter on the satellite and the users receiver, but only one particular frequency curve can be acquired at a specific point about the earth. The curve is unique for the specific location of the receiver. With radio waves as the signal an accurate computation of the navigational position of the receiver at a certain time is possible.



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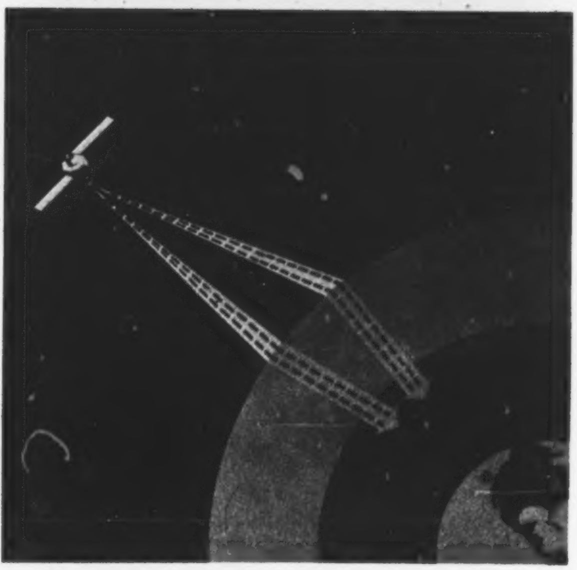
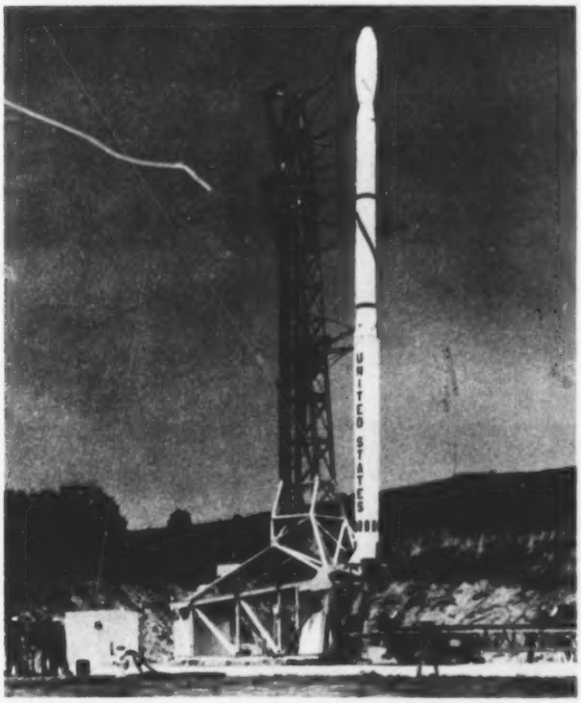
The normal position accuracy achieved through satellite navigation is better than a small fraction of a mile! Even greater accuracy is technically possible, but this is limited by several physical factors. These include ionospheric refraction which tends to distort the path of radio waves, and perturbations of orbits that lead to some uncertainties of the satellite's position. Changes of orbital paths due to uncontrollable perturbations are the primary reasons that each satellite must be provided with corrected (updated) satellite position information by radio injections twice daily from a ground control station. The near-earth orbits selected for the present system are a compromise between updating problems and functional performance. If the altitude were too high, the rate of change of frequency with time would not be large enough to provide positions accurately. On the other hand, if the altitude were much lower, the orbital perturbations would be greater and satellite lifetime in orbit might be too short for reliable use.





The Satellite System

Navigation satellites are launched into polar orbits from Vandenberg Air Force Base, California. Standard Scout vehicles (four-stage, solid fuel rockets) are used by the Air Force to boost the satellites into near-circular polar orbits at altitudes of from 450 to 700 miles. The orbits are near-circular to maintain a nearly constant satellite velocity.

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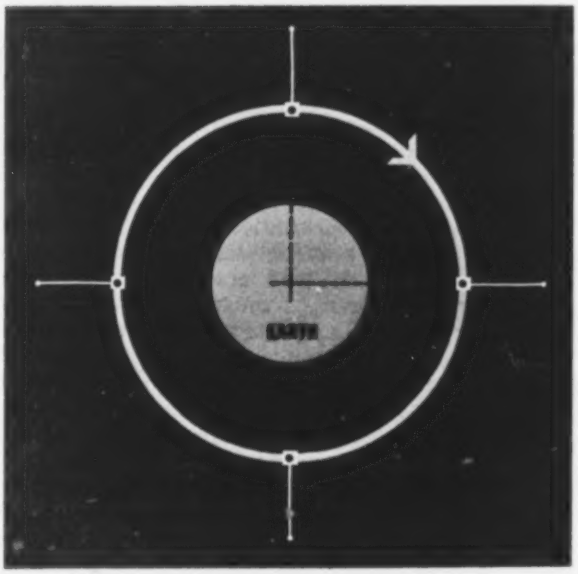
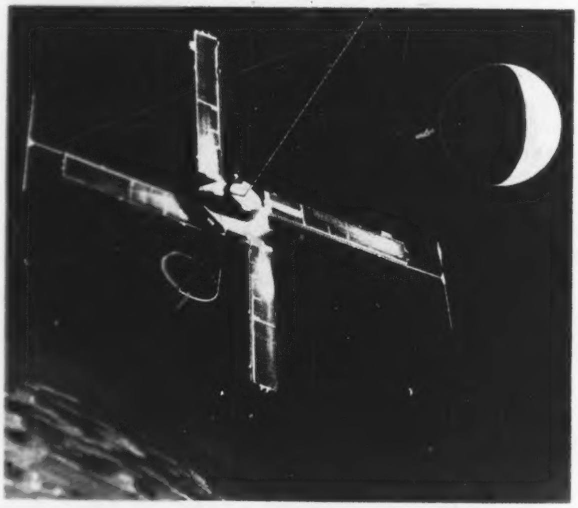
The present satellites use the principle of gravity-gradient stabilization to keep from tumbling. This method of stabilization, sometimes referred to as passive stabilization, does not require any special propulsive equipment aboard the satellite for position correction. It is effective because of the location of mass objects in the satellite. If two mass objects are connected in a dumbbell configuration and deployed in space, the system will eventually orient itself so that the long axis is always directed toward Earth's center. The shape need not necessarily be a dumbbell; the essential requirement is that the configuration have one axis of inertia which is longer than all others. The name gravity-gradient stabilization arises from the fact that the Earth's gravitational potential varies with altitude and can, therefore, provide a small righting torque to position any object with its long inertial axis pointed towards the Earth. Because of this stabilization, the transmitting antenna of a navigation satellite is directed toward Earth, thereby increasing the effective radiated power of its transmitter.



Typically, a system satellite is about the size of the large snare drum used in a marching band and weighs approximately 135 pounds. It is powered by silicon solar cells located on four extendable panels. The energy which is collected by the solar cells is then stored in batteries within the satellite. A transmitting "lampshade" antenna is mounted on the base of the satellite and receiving "rod" antennas are located at opposite tips of two of the solar panels. In orbit, the solar panels are extended to form an X with the payload in the center. A 97-foot beryllium copper boom, weighted at the end, is extended upward from the top of the spacecraft to maintain its stabilization as previously discussed.

Although successive models may differ, each satellite basically contains receiver equipment to accept injection data and operational commands from the ground, a decoder for digitizing the data, switching logic and memory banks for sorting and storing the digital data, and control circuits to cause the data to be printed at specific times in the proper format. It also carries an encoder to translate the digital data to phase modulation, ultra-stable 5-Megahertz oscillators to provide time synchronization, and 1.5 Watt transmitters to broadcast the 150 and 400-Megahertz oscillator-regulated frequencies that carry the data to Earth.



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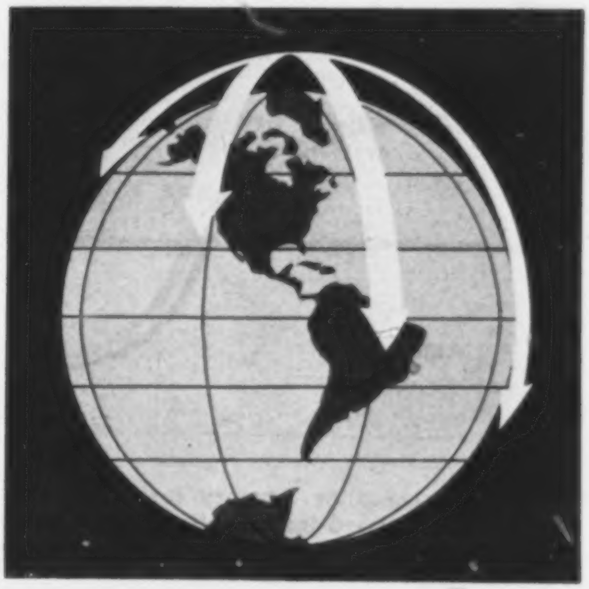


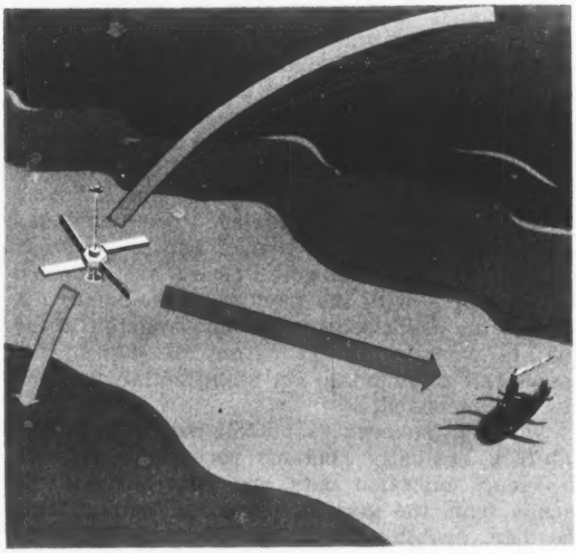
The current goal of the system is to have four satellites in near-circular polar orbits. Orbital planes would be spaced 45° apart to provide even coverage over most world locations. At orbital altitudes of approximately 600 miles, each satellite would circle the Earth in about 108 minutes. Their orbital velocity would be nearly 5 miles per second. Because the Earth rotates through 27° of longitude during the time of one orbit, a polar orbiting satellite could view every point on Earth at least once every twelve hours. With four satellites in such orbits, a navigational "fix" should be possible almost every two-hours in low latitudes and more frequently at higher altitudes.

Usage By The Fleet

Aboard ship, a navigation set activates itself as the satellite comes over the radio-horizon, and passively receives the data at the same time that it is correcting refraction errors and measuring Doppler Shift. The received data describes the instantaneous orbital position of the satellite and at the same time, the Doppler change in the received frequency. The process is automatic. The navigation set relates these two inputs to printout a fix (latitude, longitude and time) in a matter of seconds.

Two different types of shipboard navigation sets are presently in use; one, designated AN/BRN-3, is designed to meet operational and environmental needs of our Fleet Ballistic Missile submarines; the other, designated AN/SRN-9, is for surface ships. (Other types of navigation sets for aircraft and field use are under development).

The BRN-3 navigation set for submarines is completely automatic. It computes its own alerts (listing the times at which system satellites will pass within radio range of the submarine position), activates itself when a satellite approaches, receives data, computes a fix, and types out the results fro the navigator. The BRN-3 also automatically performs its own pre-pass readiness checks, and diagnoses certain trouble areas.



Prior to arrival of the satellite, the BRN-3 computes the Doppler signal it expects to receive during the satellite pass, and adjusts its receivers accordingly. This precomputation is performed using an assumed position (usually contributed by one of the other high-quality positioning systems aboard) and residual orbital data developed from a previous pass.

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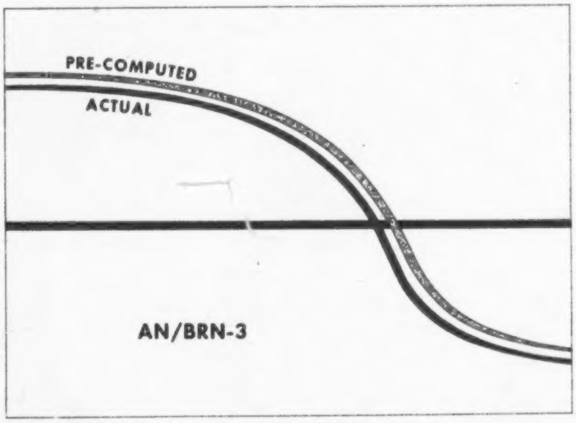
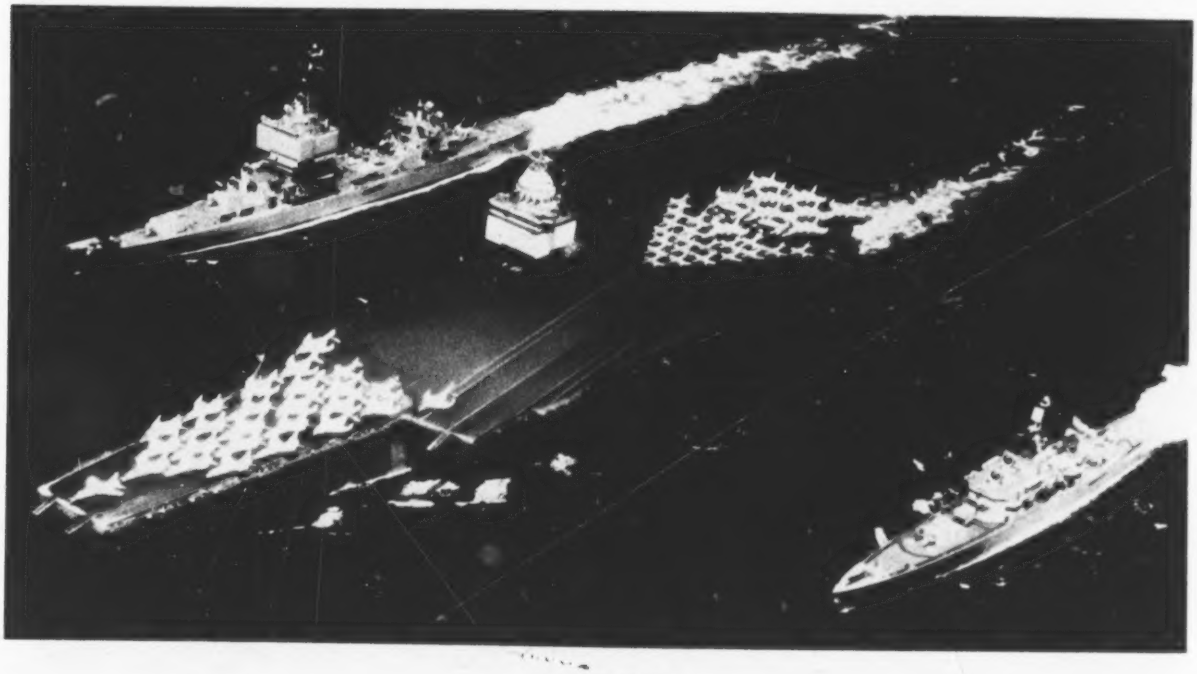
Using this precomputed information, the BRN-3 automatically acquires the satellite transmission, stores measurements of the Doppler Shift, and decodes and stores the orbital parameters being broadcast. Using these highly accurate parameters, the BRN-3 computes the exact Doppler curve that would have been received if its assumed position were correct.

The BRN-3 then compares this theoretical Doppler curve with that actually received to derive the corrections necessary to produce a navigational fix. Through a standard computer program, the BRN-3 repeatedly adjusts the assumed position of the ship until the closest possible matching of the two curves is obtained. The position at which the two curves fit most closely together is the navigation fix of the submarine position. The BRN-3 automatically types out the fix in coordinates of precise longitude, latitude, and satellite time. Precomputing, receiving, and curve fitting processes are performed almost in real time. The precise fix is retained in computer memory for use in updating the Shipboard Inertial Navigation System (SINS equipment) along with other outputs from various navigation systems on board.





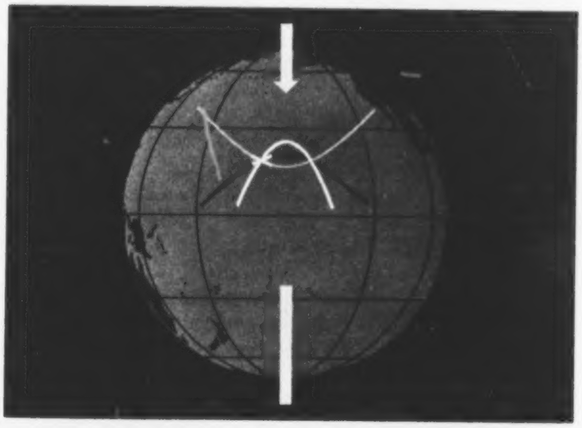
AN/SRN-9

By comparison, the AN/SRN-9 Navigation Set used on surface craft is a far less sophisticated system. It has to meet neither the need for sub-surface signal acquisition nor the problems of instantaneous interface with other navigation or precision-guidance weapon systems peculiar to our underseas fleet. Yet, the SRN-9 does provide all-weather, worldwide navigation capabilities for surface vessels.

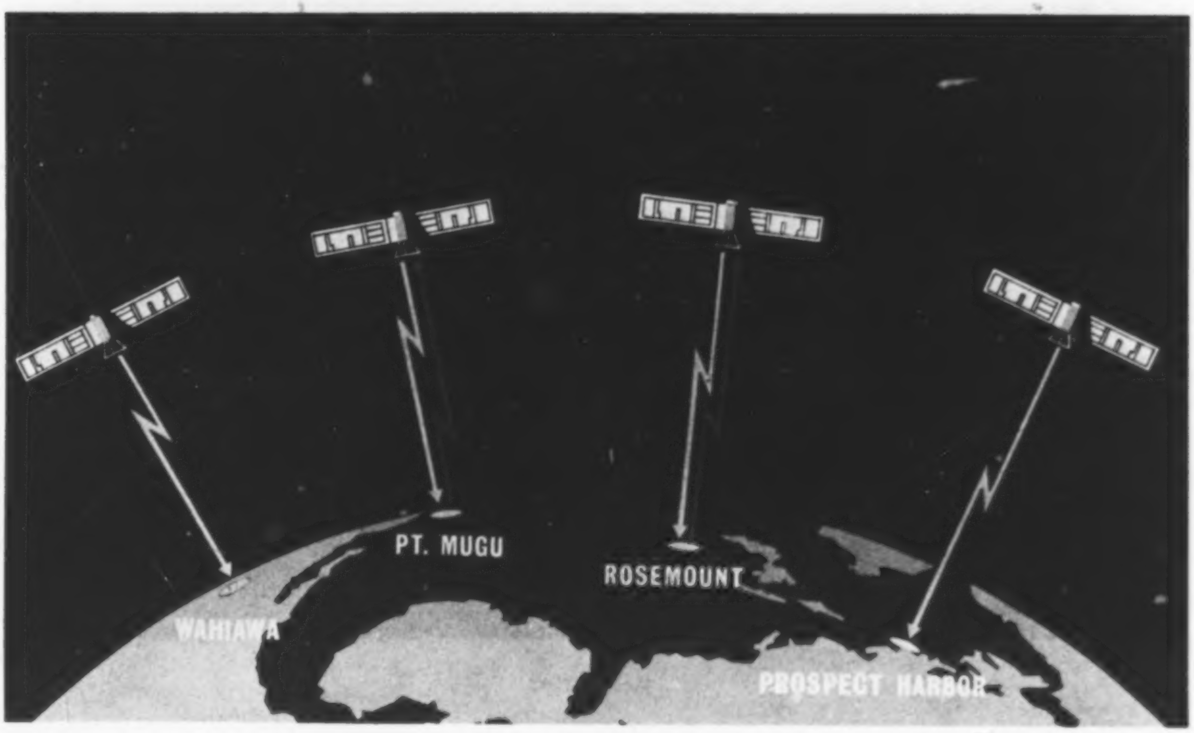
Except for receiving the satellite signals and computing the fix, the other operations mentioned above (performed automatically by the BRN-3) are accomplished manually by the ship's navigator.

Reception of at least three 2-minute intervals of data from the satellite are necessary to determine a navigation fix. The SRN-9 uses the orbital information broadcast by the satellite to update that critical part of the orbit which corresponds to the Doppler Shift received. With this information, plus a Doppler cycle-count, the SRN-9 must compute three intersecting hyperboloids of revolution. The navigation fix appears at the point on the Earth's surface where these hyperboloids intersect. The possible mirror image-point is discarded because of the effect of Earth's rotation during the listening period and the use of earlier dead reckoning fixes.

Like the BRN-3, the SRN-9 performs these computations automatically, in a matter of minutes, and prints out latitude, longitude and time according to the satellite "clock". The SRN-9 is less expensive and simpler to maintain - yet it still provides accuracies similar to the BRN-3.



Let us now examine the operation of the system in more detail.



The Ground Network

The Navy Astronautics Group operates the Navigation Satellite System from its headquarters at Point Mugu, California. In addition to the tracking and injection station atop Laguna Peak, overlooking Point Mugu, there are three other ground facilities: detachment A, located at Prospect Harbor on the Maine Coast, detachment B, also an injection facility, located at Rosemount, Minnesota, and detachment C, at Wahiawa, Oahu, Hawaii. These tracking and injection facilities are connected to a centralized control center and computer complex at Point Mugu by high-speed data communication lines.

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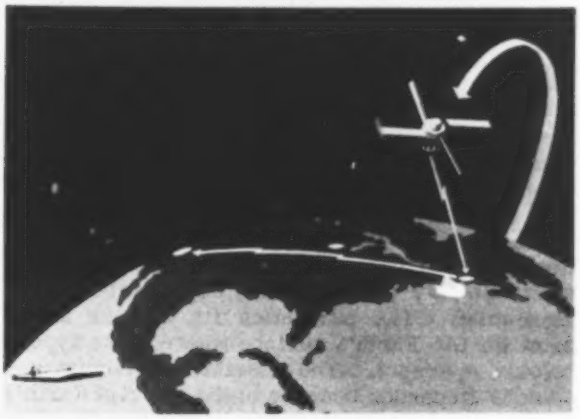
Tracking

Tracking stations record Doppler observations and memory readouts received during specific satellite passes and report this information to the computer center. With this data, the ground facility can determine the satellite's exact position and predict its future position for the next 16 hours.



Computer Operations

The computer center prepares new message data to be injected into each satellite every twelve hours for broadcast to the fleet. Computers use the latest Doppler observations reported by the tracking stations to reconstruct the present orbit. From this, and from information derived from recorded observations of thousands of passes, the main computer extrapolates predicted orbital positions which the satellites will traverse while broadcasting the new data. These predictions, timed to come true the instant they are broadcast, are injected along with operational commands to the satellite.

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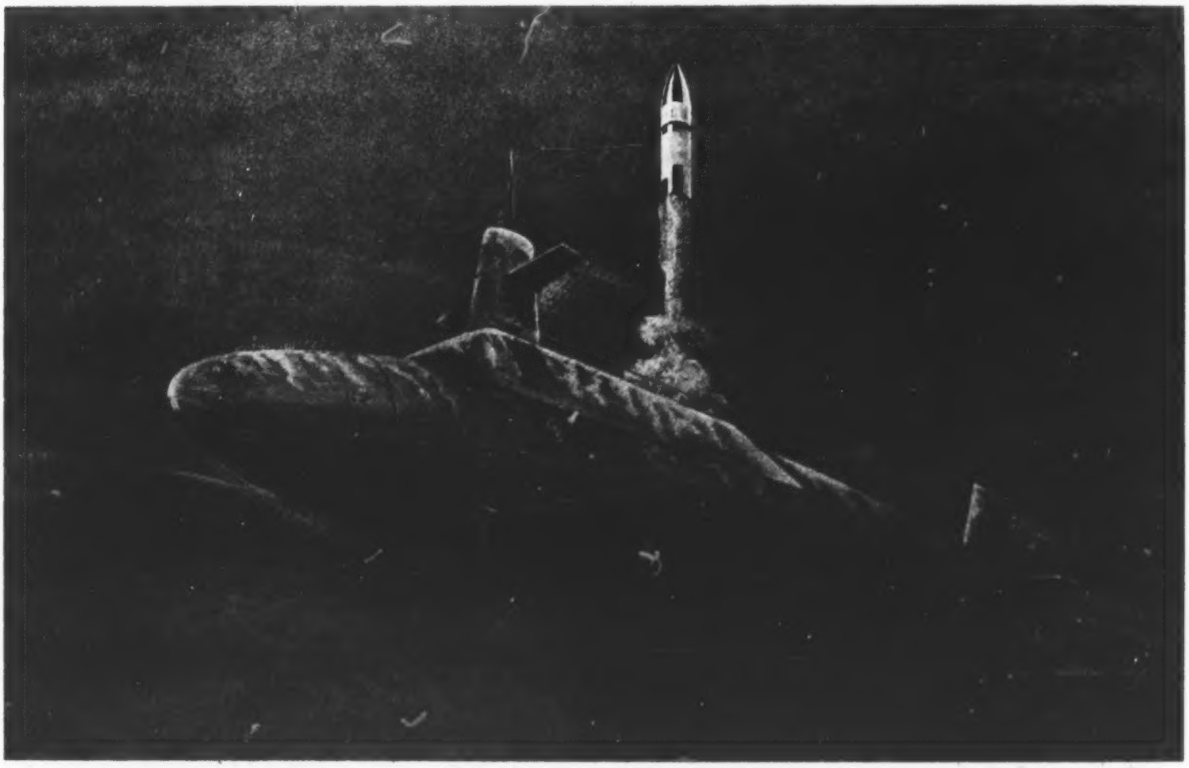
Injection

Injection facilities use precomputed data to aim the antenna, to control digital equipment during injection, and to inject fresh data into each satellite. The injection facility transmits the injection message to each satellite at a precise time for storage into the satellite memory. Total injection takes place in a little more than a quarter of a minute. After injection, the station computer immediately checks the first readout received to make sure that the satellite is broadcasting the new information correctly.

The satellite receives, sorts and stores injection data, and immediately commences transmitting readouts to Earth, simultaneously phase-modulated on two carrier frequencies. Enough data is stored in the satellite's memory to last for 16 hours of consecutive 2-minute broadcasts describing its known orbital positions as it revolves around Earth.



Through utilization of the system just described and of systems to follow, a navigator need no longer be uncertain of his location.

Navigation systems, perhaps those carried on future satellites at synchronous altitude, will ultimately decrease time intervals between repeat position information. Even now, navigation from a synchronous satellite by measurement of the range and direction of the customer is being studied.

Whether the use is safety in transportation or battlefield accuracy, a highly accurate and reliable satellite navigation system has been developed by the Navy. This is particularly vital to the Navy in carrying out its missions at sea. Our mobile gun platforms and sea-launched missiles can be only as accurate as the known positions of their launch sites.

Today, the Navy Navigation Satellite System enables fleet units to pinpoint their true positions more accurately than ever before. Present-day users of this system can almost instantly establish their location anywhere on Earth at any time of day or night, in any kind of weather or battle conditions . . . a navigator's age-old dream has come true.

CHAPTER 16

SPACE DEFENSE

NAVAL SPACE SURVEILLANCE SYSTEM

One of the Nation's early interests relating to space was to detect and predict the orbits of all satellites, friend or foe, radiating or silent for the main purpose of knowing what was whirling about Earth.

Back in 1957 this wasn't much of a task because there was only one man-made satellite (Sputnik) in orbit, and everyone knew its origin. By way of contrast today, the number of objects observed in space during a typical 30-day period is near 300,000 (over 10,000 sightings per day). This is not meant to imply that there are anywhere near this number of satellites in orbit. These sightings include the debris associated with various orbital payloads and launching vehicles. This number also includes repeated sightings of the same satellites and debris as they continue to circle the Earth. At the present time, however, there are over 1,000 separate detectable man-made objects in orbit. This fact makes apparent the need for a system that can detect and keep track of these orbiting bodies, many of which are of interest to our fleet and to our national space programs.

We know that one military application of space systems can take the form of reconnaissance satellites. One can surmise that a particular emphasis in this application is locating our fleet. The initial steps in countering this threat are (1) early identification of all satellites, and (2) their continued tracking, and (3) providing our force commanders with prompt and accurate information on selected satellites thereby permitting them to take appropriate evasive or defensive action including neutralization of the satellite. To accomplish this tracking of space objects, the Naval Research Laboratory (NRL) started development work in 1958 which has led to the Naval Space Surveillance System (NAVSPASUR).

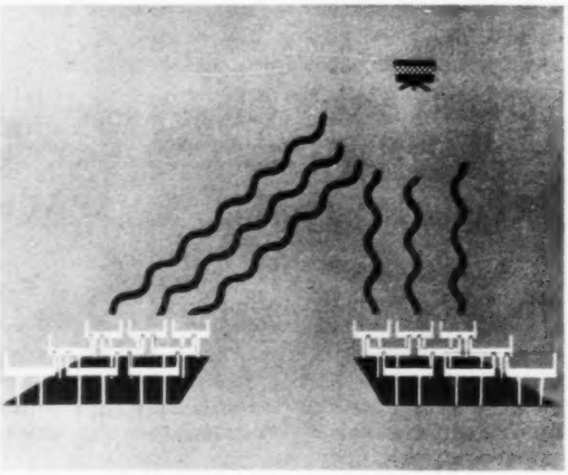
The NAVSPASUR system consists of two subsystems: (1) the detection subsystem of 3 transmitter sites and 6 receiver sites; and (2) the headquarters computation and analysis center.

NAVSPASUR works on an interferometer principle by which waves reflected by a target will vary in phase at a receiver site. In NAVSPASUR, radio transmitters produce a thin fan-shaped beam of energy directed vertically upward. The beam is very narrow in the North-South direction with a maximum of 4 miles width at 8,000 miles altitude, and very wide in the East-West direction (coast to coast).

NAVAL
SPACE
SURVEILLANCE
SYSTEM

A satellite or any other object passing through this beam reflects a part of the transmitted energy back to the receiver sites. Such a received signal indicates the passage of the object. Through the use of many pairs of interferometer antennas to compare phase relationships at the receiver sites, a precise direction of travel of the object is obtained.

In addition, a Doppler shift (see Chapter 15) in the reflected signal occurs due to the object traveling through the beam. The alert antenna (the longest and most sensitive at the receiver sites) automatically tunes additional interferometers to the reflected signal. Many pairs of antennas are used on base lines as short as two feet and as long as a mile. These antennas make accurate phase measurements to resolve ambiguities and provide accuracy. Each receiver site has rows of rod antennas (dipoles) oriented in the North-South direction to give signals for computation of zenith angle.



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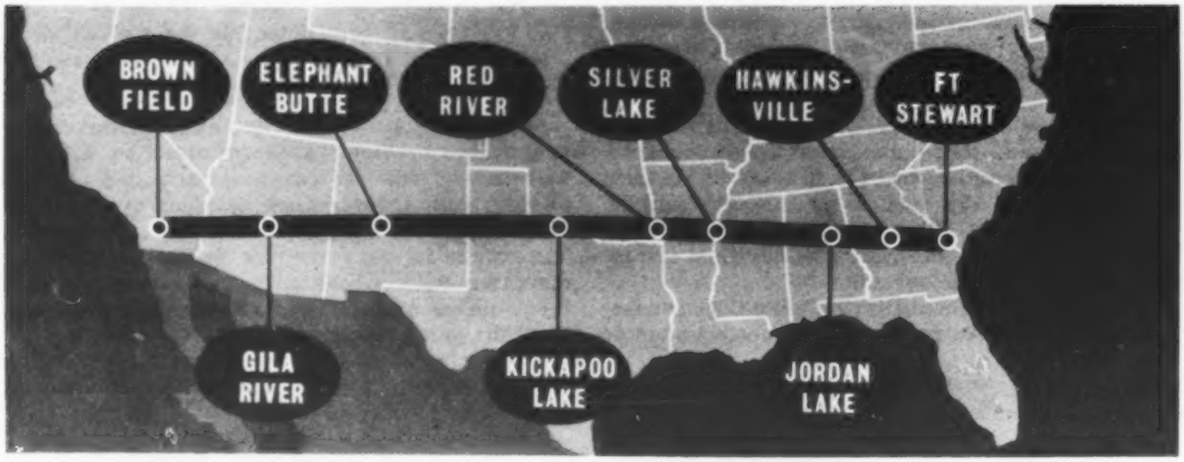
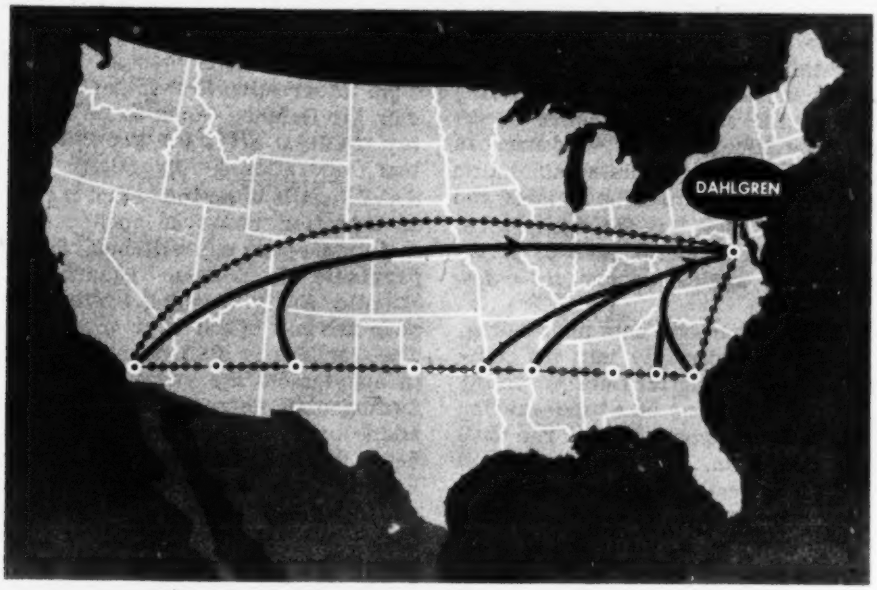


NAVSPASUR SUBSYSTEMS

The detection subsystem stretches across the southern part of the United States from San Diego, California, to Fort Stewart, Georgia. The network is laid out on a great circle at approximately 33 degrees inclination. In this network of field stations the primary transmitter is located at Kickapoo Lake, Texas, and radiates on a frequency of 216.98 MegaHertz with a maximum power of one megawatt into a two-mile long antenna system! Two other transmitters are located at Gila River, Arizona, and at Jordan Lake, Alabama; they radiate on the same frequency but at a power of 50 kilowatts into shorter antennas.

Alternating with the transmitter sites in the field station network, are the receiving stations, located at San Diego, California; Elephant Butte, New Mexico; Red River, Arkansas; Silver Lake, Mississippi; Hawkinsville, Georgia; and at Fort Stewart, Georgia.



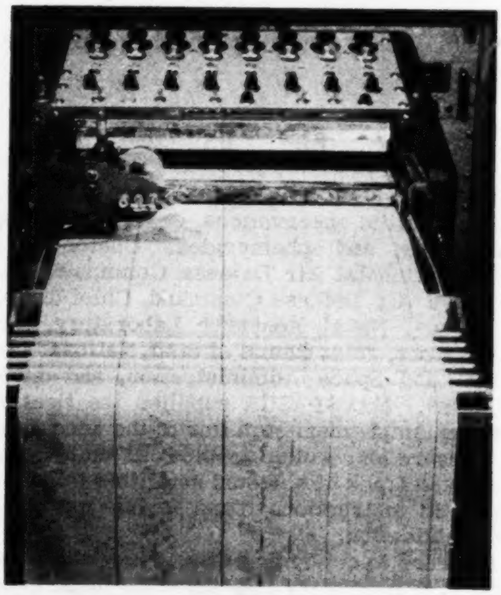
Multiple interferometers at the receiver sites are used to determine zenith angles. These phase angle data (differences between each interferometer pair of antennas) are transmitted in analog form using a tone telemetry system over leased telephone lines from each field station to the data processing subsystem, NAVSPASUR Headquarters at Dahlgren, Virginia.

* * *

DATA PROCESSING

At Dahlgren, the data are changed to digital form by the Automatic Digital Data Assembly System (ADDAS) for computer processing.

In the ADDAS, phase data first go to the bit assembler (one for each receiver station) where the data are checked for transmission error. Time is next associated with these data by a clock calibrated by the National Bureau of Standards to an accuracy greater than one one-hundredth of a second. Following this, the data flow simultaneously in three directions. Firstly, all the data from the six bit assemblers are recorded on magnetic tape. This includes all the actual satellite-pass signals plus incidental noise and interference. This ensures backup in case of data loss later in the reduction and processing phase. Secondly, data go into an analog conversion unit for visual display of all incoming phase data on a graphic recorder for individual monitoring as required. Thirdly, these data also go to the message assembler where satellite signals are separated from spurious noise and other such concurrently collected interference.



Following this, processed data are recorded on an ADDAS tape unit (a magnetic tape record of only actual satellite signals). This tape provides data backup in the event that the transfer channel between ADDAS and the computers breakdown. At the same time, data are fed into one of the two computers for immediate calculation of zenith angles which are machine printed and then put on magnetic tape by the computers. Consumed time from a satellite pass to printing of actual zenith angles occurs in a few seconds.

As mentioned, for immediate data processing, phase information is fed directly into the computer from the Automatic Digital Data Assembly System (ADDAS). This is done on a time-sharing basis. Daily operational programs are run until a satellite pass comes in. A control unit will then shift from the operational program to the ADDAS data reduction program to process the pass. This task completed, control will shift back to the operational program until another pass is received. This time-sharing system allows for immediate print-out of satellite crossings of the NAVSPASUR fence while using computer running time most profitably.

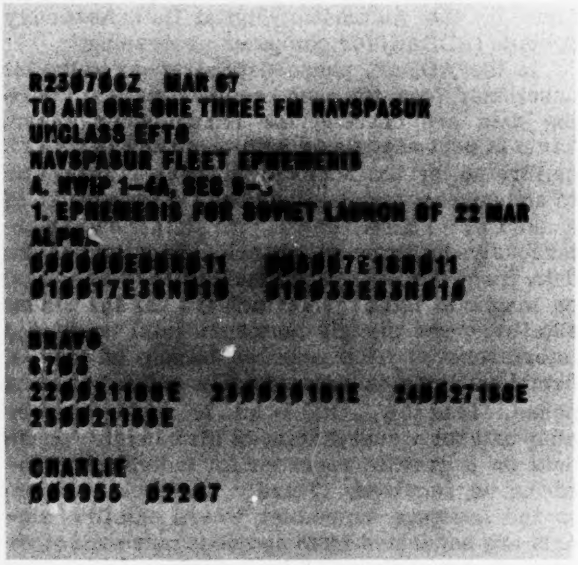
Through such satellite observations, the orbital elements (see Chapter 5) are determined. In the case of new launches, accurate orbital elements are calculated from passes on opposite sides of the orbit. From the latest elements, new fence crossing predictions are made and transmitted to any customers. All customer output is derived from the latest set of orbital elements and updated with every new observation.

FLEET USE

This computed output consists of orbital elements, satellite observations, equator crossings, look angles, and ephemerides. Customers include Continental Air Defense Command, North American Air Defense Command, Chief of Naval Operations, Naval Research Laboratory, Naval Observatory, Joint Chiefs of Staff, National Aeronautics and Space Administration, and missile test sites. NAVSPASUR supplies the fleet by a message emphemeris similar to the accompanying illustration, which enables all units to plot the ground track of selected satellites in accordance with instructions found in the appropriate Navy publication.

In order to determine when a new object is in orbit, it is necessary to predict the fence crossing of all known objects. Anytime an object comes through the fence that cannot be immediately identified, it is subjected to further analysis. This information is then sent to the North American Air Defense Command's Space Defense Center (NORAD SDC) for processing since NORAD has operational direction of NAVSPASUR. NAVSPASUR is an important member of the team of detection networks and special sensors that maintain space surveillance. The biggest are the parabolic fixed-beam radars of the Ballistic Missile Early Warning Systems (BMEWS) that scan the air space over the northern latitudes. The Air Force also operates other giant radars to supplement the coverage of the BMEWS. The Smithsonian Astrophysical Observatory provides additional coverage with 13 cameras. Precise 3-ton Baker-Nunn cameras, operated by the Air Force, have photographed satellites more than 20,000 miles distant. In general operations, the Space Defense Center at Colorado Springs has about 150 tracking stations feeding it information.

Most orbiting objects are quickly identified by one or more of the detection networks, but if an object cannot be positively identified by NAVSPASUR or associated with a particular launch, then interpretive information is also sent along with associated observations to NORAD SDC on a continuing basis.



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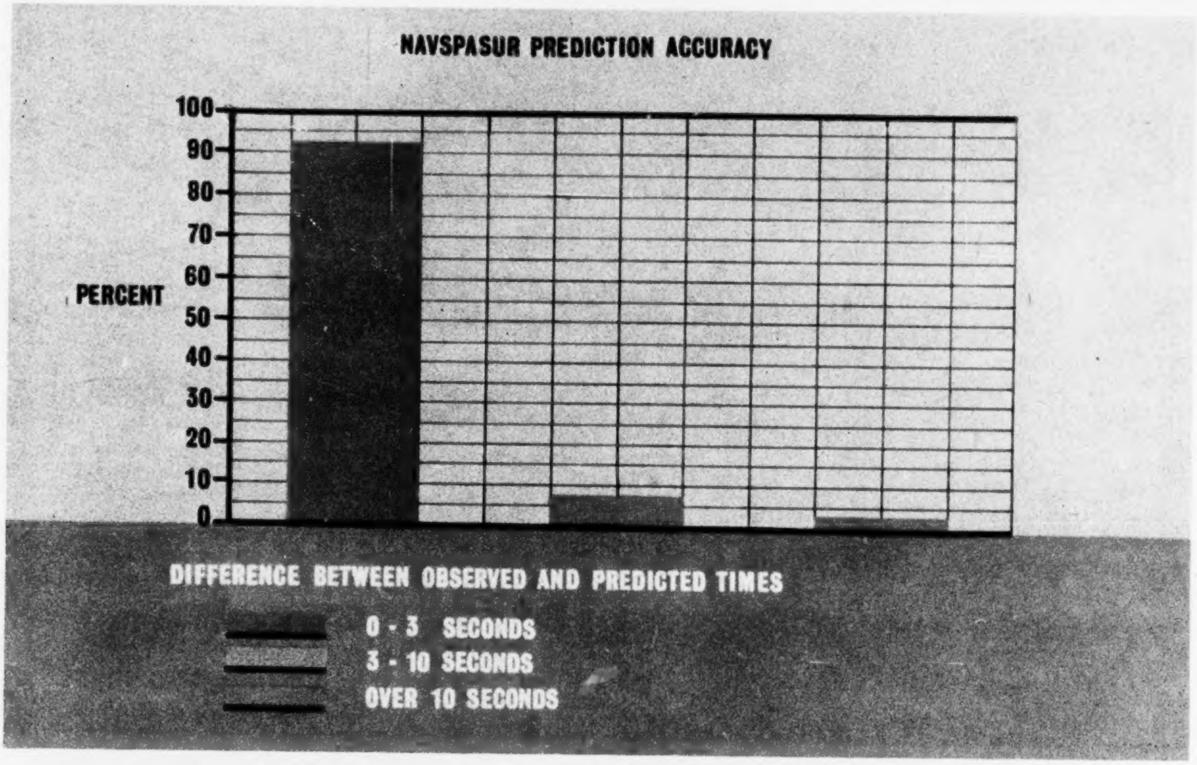

The difference between predicted times and observed times for about 94 percent of all observations ranges between 0 to 3 seconds. The remaining six percent of the observations that fall outside of the 0 to 3 second accuracy limit do not represent poor prediction accuracy but are due to (1) high apogee satellites that are lunar-perturbed, (2) to satellites in the final stages of decay where it is difficult to predict their orbit, and (3) to new satellite launches where an accurate set of orbital elements has not been obtained.

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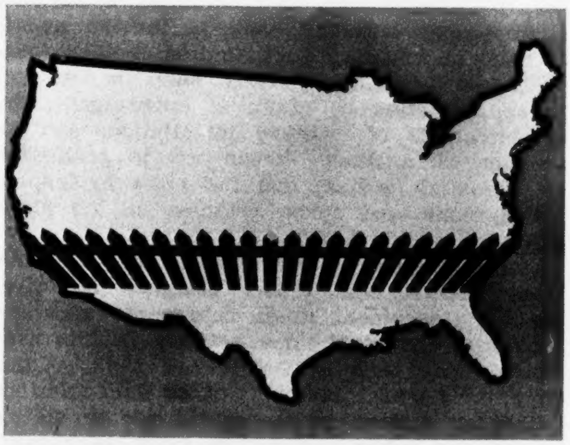
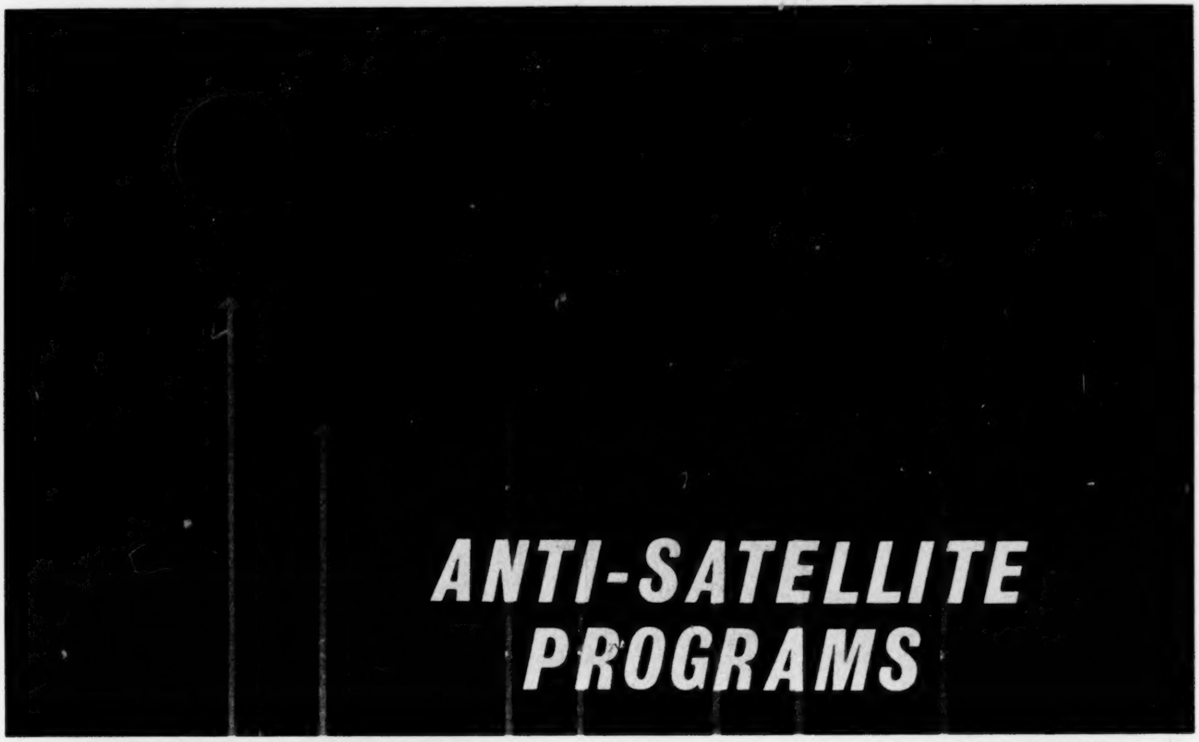
One of the Navy's prime assets has always been its power to roam the seas of the world uncontested. With the coming of military satellite operations, this asset is being severely threatened. NAVSPASUR offers information to the fleet on when and where to detect space threats so that by forewarning they may be effectively countered.

The Naval Space Surveillance System continues to operate successfully as a true space sentinel standing watch across the Southern boundary of the United States, an example of external vigilance.



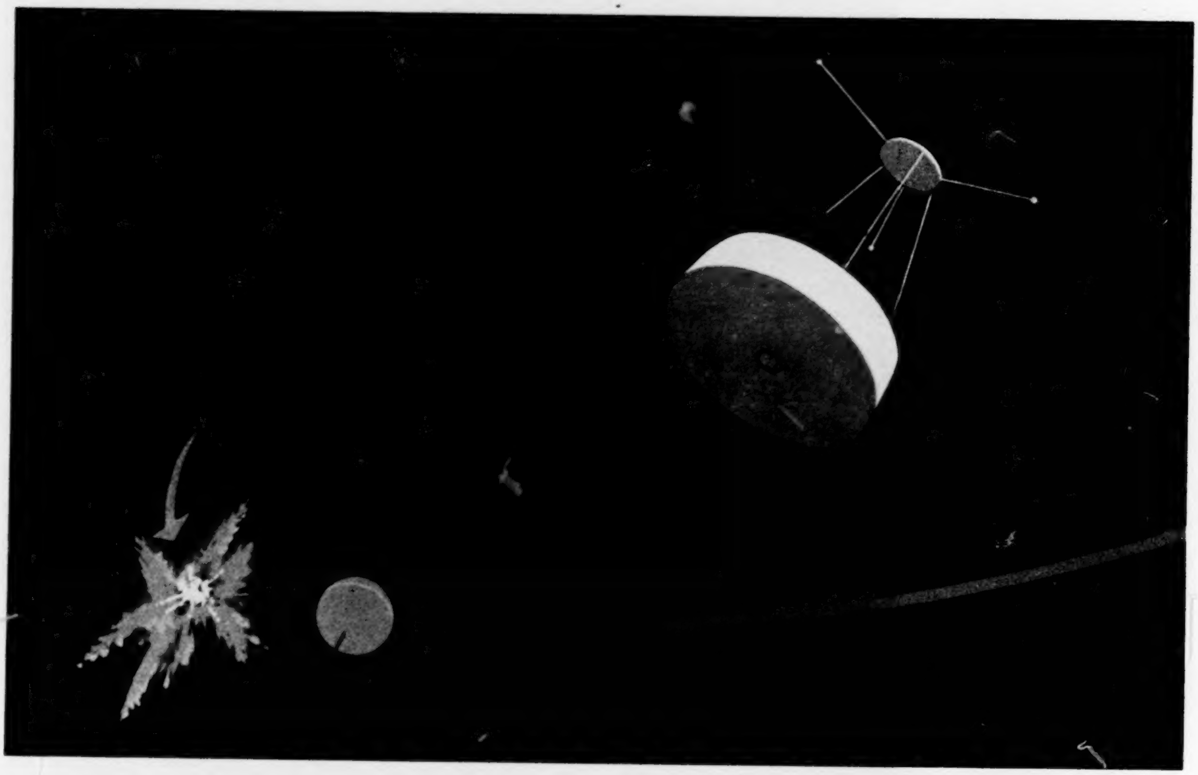


ANTI-SATELLITE PROGRAMS

As a result of the signing of the space Treaty ("Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and other Celestial Bodies") on 27 January 1967, sixty sovereign countries of the United Nations have agreed that utilization of outer space should be directed toward the peaceful aspects of mankind. In more detail the signatories agreed that the exploitation and use of outer space and other celestial bodies shall be for the benefit of mankind without discrimination; neither outer space nor celestial bodies shall be subject to appropriation by claim of sovereignty; the establishment of military installations and the conduct of military maneuvers is prohibited on celestial bodies; and the right to inspect installations and space vehicles on the Moon and other celestial bodies is assured.

Although proper ratification must be obtained before this treaty becomes effective, the very document itself represents a culmination of United Nations activity in this area which dates back to October of 1963. At that time, the General Assembly of the United Nations called on nations of the world not to station nuclear or other weapons of mass destruction in outer space. Two months later the Assembly adopted a declaration of legal principles which arrived at offering a means to govern activities in outer space. Thus, the 1967 Space treaty clearly indicates the desire of mankind to create an environment of peace in the vast expanses of space.

However, documents and treaties as exemplified by the Space Treaty often have a way of being reduced to mere thoughts and desires rather than being advanced to actual practice. This is especially noted when the national interests of any nation are restricted by a particular international agreement. In other words, if any nation should decide that it would be vital to their interests to maintain an offensive weapon system utilizing the outer space arena, the fact that a treaty exists without physical enforcement measures to prohibit such activitity would hardly preclude the creation of the offensive space system. It therefore becomes necessary for the United States to recognize the possible threat that would be posed by any space-borne weapon or associated military space system that could limit the effectiveness of current Earth-based offensive and defensive weapons.



Any defensive approach necessary to counter a space weapon must include the classical elements of a defensive weapon system: detection, identification, interception and neutralization or destruction. The first two categories, dection and identification, have previously been discussed in detail while considering the Naval Space Surveillance System (NAVSPASUR). The proper application of the information supplied from this or other detection and identification systems compels one to consider how might an anti-satellite system be deployed.

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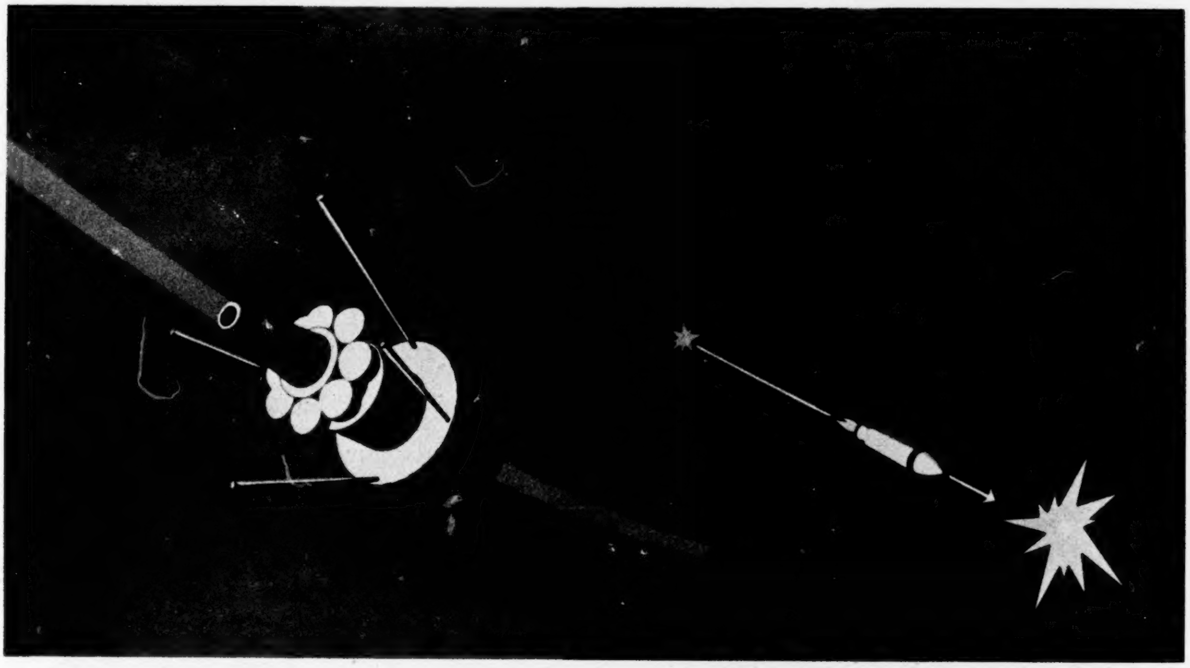
One potential approach to provide an anti-satellite weapon exists in terms of adapting a current weapon systems for this purpose. This concept applies to a vertically-rising interceptor similar to the anti-ballistic missile that is launched to the altitude of the enemy satellite in or near the plane of its orbit. The requirements for providing a launch platform to handle this particular approach might be satified by associating this anti-weapon system with the advanced anti-ballistic missile (ABM) program (e.g. NIKE X), thus permitting the ground launch sites, necessary for providing support to any ABM system, to serve a second command function. The requirements might also be satisfied by Air Force use of operational missiles.

However, the Navy might well consider study and development, if approved, of its current ballistic missiles (POLARIS and the future POSEIDON) into an advanced anti-satellite weapon along similar lines as an ABM system, which would provide the fleet and the Nation with mobile launch platforms. Such a mobile network of launch pads offer the distinct advantage of flexibility necessary to reach any orbit-inclination for interception of the enemy satellite from water launch sites. In general, this can be better accomplished from water launch sites because water covers nearly 75% of the globe.



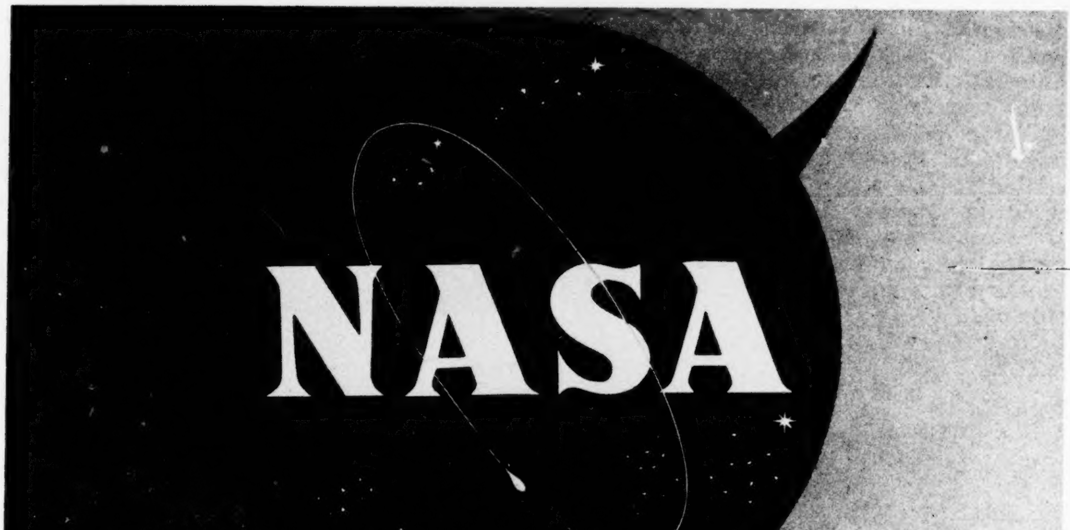
This type of anti-satellite operation holds special interest for the Navy. Not only would it offer the Navy the opportunity to continue operations without the harrassment of spaceborne weapons, but would also permit the Navy to assist the nation's defensive posture by deploying mobile bases at sea. The mobile bases may become extremely desirable when one considers the fact that all orbiting satellites must pass over ocean areas, but enemy satellites could be programmed for minimum passes over U.S. land areas containing fixed-position anti-space weapons. Thus, submarines located at unknown positions under the surface of the oceans could offer a serious threat to any nation planning to orbit space weapon devices. Additional advantages realized from sea-based launch sites include increased availability in terms of freedom from blast/fallout damage, reduced warhead employment restrictions, and minimum dependence upon complex surface equipment.

One extension of anti-satellite operations might include orbiting inspection stations in space to keep a close watch on all satellites. Such an approach using either a manned or unmanned inspector must include the ability to rendezvous with a satellite, conduct the inspection, and if necessary permit suitable actions to be accomplished. The interim situation, however, requires that our nation possess a defensive system within current state-of-the-art technology as a means of retaliating against the threat of an orbiting weapon. In fact our nation may not wait until sophisticated space-borne inspection systems are developed. The very threat of a future war involving the environment of space dictates the need for adequate space defenses that can be use on a short-time basis.

The United Nations Space Treaty represents a big step toward the day when the peaceful intentions of mankind will prevail. The interim situation must therefore be viewed in terms of how close mankind is to the realization of this day of utopia. Until all nations agree, both in thought and deed, upon the peaceful uses of outer space, it is mandatory that the United States maintain a strong defensive arm and be prepared to conduct anti-satellite operations.

CHAPTER 17

THE FUTURE



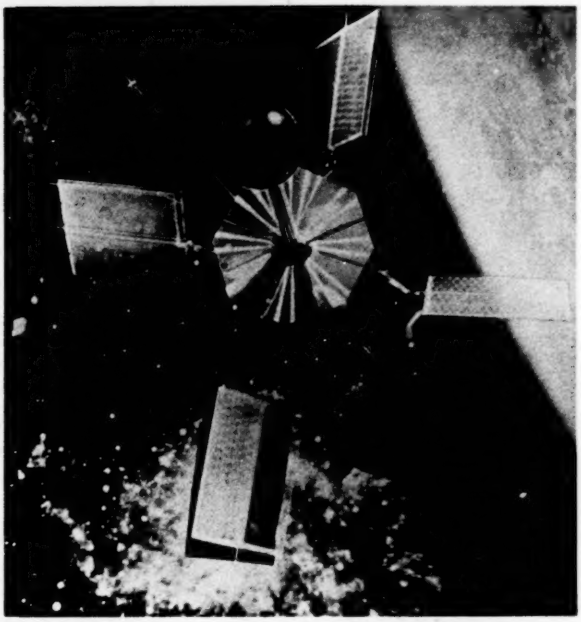
NASA

Although diverse scientific activity leading to space exploration had been underway for decades, it was in 1958, reacting from the stimulus of Sputnik, that the United States consolidated its civilian space activities under one coordinating agency. This coordinating organization was the National Aeronautics and Space Administration (NASA), whose nucleus was formed from the old National Advisory Committee for Aeronautics and the larger part of the Army's Ballistic Missile Group.

As a national agency, NASA is responsible to Congress for organizing and administering the nation's civilian efforts in space. The costs of this effort can be measured by the NASA budget (approximately five billion dollars annually). Over eighty per cent of NASA's effort is applied to research and development. The remainder is used in administration, communications, data-handling systems, and limited production of prototype space equipment.

Under the administration of NASA, this country has successfully explored not only space in the immediate vicinity of Earth, but also near the Moon, Mars, Venus, and from a respectful distance, the Sun. These space investigations have been most fruitful, but they have only scratched the unknowns within our solar system as a good beginning for the exploration of space.

This age of space exploration began with successful launching of unmanned spacecraft to investigate that realm immediately beyond the Earth's atmosphere. These near-Earth satellites contained sophisticated sensors and computing mechanisms but were limited in payload weight and capacity. Micro-miniaturization of spacecraft components has relieved these restrictions to a great degree, but extended missions with broader objectives have brought payload limitations to the fore again with a need to revaluate each spacecraft component. Some designers believe the lightest, most versatile and most reliable combination of sensors and computers may be man, himself. Speaking as a design engineer, one might say man is an "off-the-shelf" item occurring in large quantity. But, unfortunately, man's "package" and "power systems" are not at all well-suited to the space environment, as was discussed in Chapter Seven, Bioastronautics. The absence of oxygen, pressure, food, water, or gravity, coupled with extremes of heat and cold, make space an extremely hostile environment for man.



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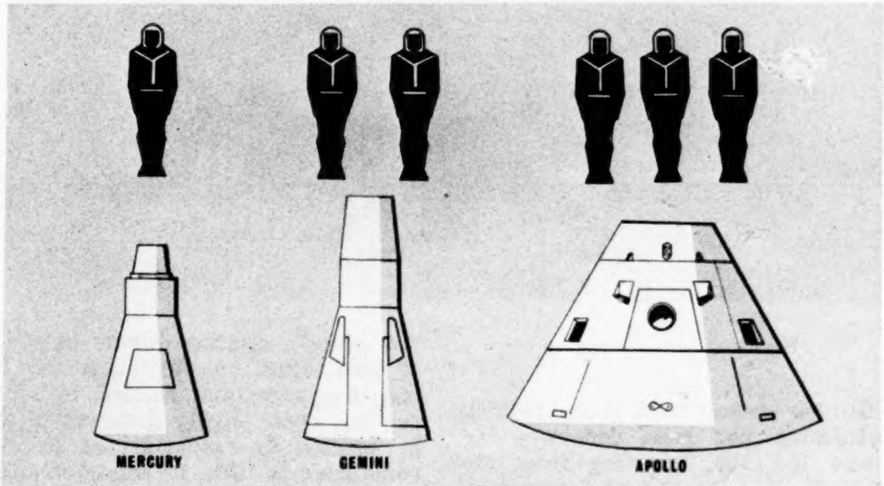

Devices which will enable man to exist in space have been in development for many years. These life-support systems have demonstrated their feasibility throughout the one-man Mercury Program and the two-man Gemini Program. As our nation strives for greater involvement of man in space, we will witness progress in the three-man Apollo Moon Program, as well as that of the more distant Apollo Applications Orbiting Workshop and the Manned Orbiting Laboratory. In these programs man will use the information provided by the earlier unmanned space probes and observatories to prepare himself to act more effectively as an on-site observer and experimenter. He will be able to witness and compare phenomena over a period of time in an environment which cannot be simulated completely on Earth.

Many of the preliminary problems of long-duration space flight will be solved in the Manned Orbiting Laboratory (MOL). The MOL project is under military direction (Air Force). It will carry considerable original experimentation that will advance the state-of-the-art in manned space flights leading to more ambitious civilian efforts.

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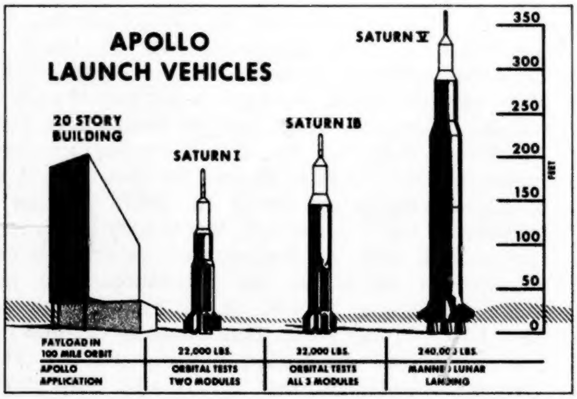
The Apollo Applications Program (AAP) will be devoted to furthering the scientific exploration of the Earth's environment in space and man's adaptability to that environment. Indeed, the success of this AAP program may indicate the direction of this nation's space efforts for many years to come. As the name of the program implies, the Apollo Applications Program will use the hardware and techniques already developed by the Apollo Project of putting a man on the Moon. The AAP concept will make efficient use of the vehicles and structures already developed for project Apollo by launching back-up vehicles with structures and support systems already used in the major Apollo launch. As part of the AAP, satellite-borne sensors will monitor daily activities on Earth. Explorations of the Moon for two weeks or longer will be conducted. Manned flights lasting a year or longer, and possibly manned journeys to Mars and other planets will be attempted. A launch rate of four of the uprated Saturn I and Saturn V boosters is planned annually. The uprated Saturn I can lift up to 40,000 pounds of payload into near-Earth orbits, and the Saturn V up to 285,000 pounds around the Earth or about 95,000 pounds to the Moon. The basic project Apollo systems will be modified to meet the initial needs of these new space programs without the necessity of developing all new hardware.

Specific plans for AAP include:

(a) Converting the second stage of the uprated Saturn I launch vehicle into a 10,000 cubic foot orbital workshop.



(b) Developing a two-gas life support system that can keep men in orbit for a year or more.

(c) Developing a nuclear powered rocket stage for space use (see Chapter Six).

(d) Modifying the project Apollo lunar module so that it can support men on the Moon for six weeks or longer.

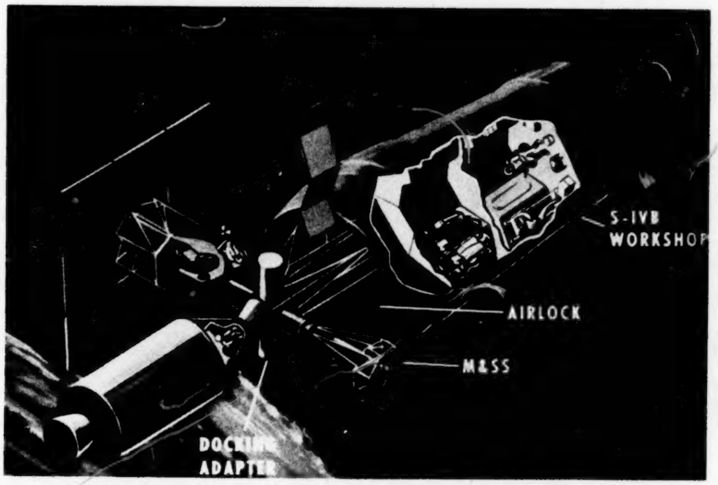
(e) Modifying the Apollo spacecraft so that it can carry up to six men for short duration ferry and resupply missions, returning to Earth for dry-land landings and re-use.

(f) Developing a manned solar telescope system to study solar activity from space.

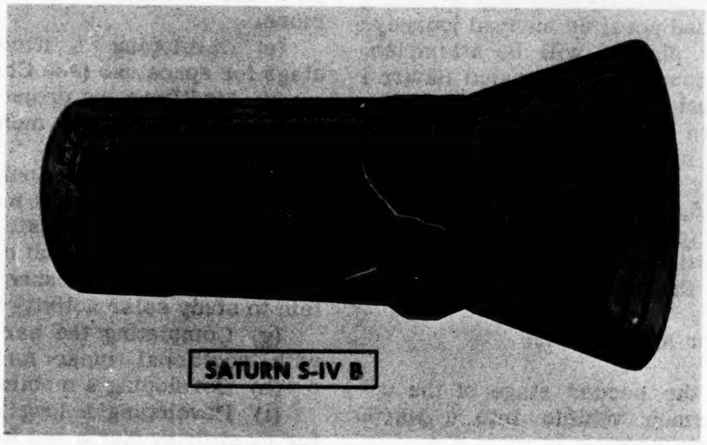
(g) Completing the cartography of the Moon with additional lunar mapping and surveying.

(h) Developing a mobile lunar vehicle.

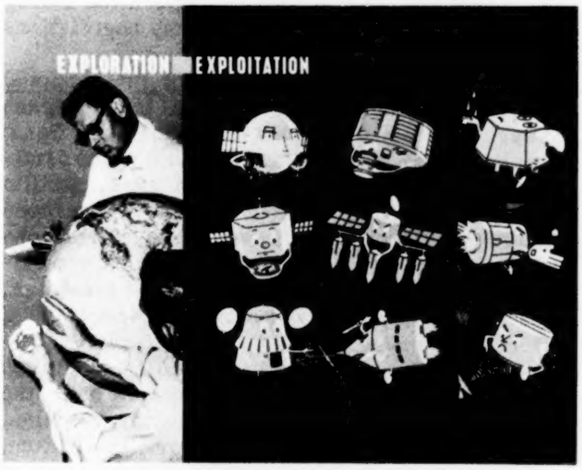
(i) Developing a long list of special sensors for monitoring Earth and lunar activities.



In the past, when a space system or experiment was to be tested, a new satellite was usually built specifically for that purpose. For the AAP, a new approach will be taken. It involves orbiting a huge, manned space workshop that is used to test a series of experiments. Then, as these are perfected, separate satellites may be developed to exploit these experiments. NASA hopes to have its first space workshop in orbit in 1969. Instead of building a new spacecraft, the agency is modifying a fuel tank in the uprated Saturn I launch vehicle to serve as the workshop. The tank stage, called a S-IVB, is 58.4 feet high and 21.7 feet in diameter. This stage is divided into two tanks, one containing oxygen and the other hydrogen. Initially, the S-IVB will help power the uprated Saturn I to put the three-men Apollo spacecraft into an approximately 250-mile high orbit around the Earth. Once its fuel has been expended and while it is attached to the Apollo spacecraft, the hydrogen tank on the S-IVB will be cleaned automatically to serve as the workshop. The astronauts will enter the workshop from the Apollo spacecraft through a special air-lock. A life-support system is being developed for the workshop to enable the astronauts to live in a shirtsleeve environment without being burdened by their cumbersome flight suits. Plans call for keeping the work shop in space for two to three years as a minimum. The astronauts' initial stay in the workshop will last about 28 days. At that time, they will re-enter the Apollo spacecraft, detach from the orbiting workshop, and return to Earth. The workshop will be revisited with astronauts gradually increasing the length of time they remain in space to a year or longer.


SATURN S-IV B

Our nation's welfare and general scientific knowledge advance with each success in space exploration, including military applications. For example, satellite concepts previously used exclusively for research and exploration are being reshaped to include surveillance sensors which will monitor the Earth's resources. These sensors, integrated into a satellite system, could record yields on a global basis; measure water resources by checking stream flows, and snow quantities; lake forestry yields could be assessed; disease in forests and crops could be detected; and a limited knowledge of sub-surface minerals could be obtained. Famines and surpluses in food crops could be predicted very easily on a global basis and remedial steps taken before a crisis develops; floods or droughts could be anticipated; geologists would know where to look for mineral deposits.



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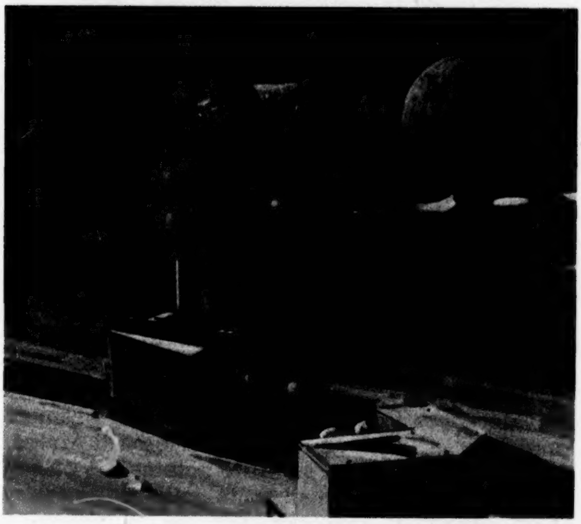
These successful exploitations of space will prove valuable to our nation, and they will be also important to other nations. What is the prospect for cooperation in space on the international level?



On the international level, the dominant space roles assumed by the United States and the Soviet Union during the immediate years following Sputnik represented a monopoly on space research. The two giants controlled all significant aspects of space exploration, and little room remained for contributions from other sovereign states. However, the last five years have witnessed a remarkable change. Many nations have showed some interest in space. Groups of nations have formed space organizations to accomplish specific goals, and many have begun to adjust their educational systems to produce space-oriented personnel. Modern states now realize that rewards in the Space Age can accrue for any nation which works at it.

One aspect of this new international space interest is the normal desire of nations to involve themselves in the "attractive" activity of space exploitation. The prestige that occurs from active participation in space projects is, of itself, enough reason for the increase of space interest among nations. Many certainly desire to claim some responsibility, albeit quite small, for the successful landing of both manned and unmanned payloads upon the Moon or the planets and our solar system. There are other reasons, however, for although few nations can afford the costs involved in establishing complete space facilities, many countries may make scientific and technical contributions to the aerospace field. A nation with scientific ability can share its expertise, and, by participation, derive economic benefits from the many scientific advances associated with space technology. Opportunities also exist for nations with limited technology. These nations may become users of space-borne systems and the new technology (for example, receiving communications from a satellite while contributing only the land installations necessary to process the information). Cooperation among nations in space is the goal of many negotiations within the United States.

Indications of the existence of international cooperation can be readily seen in the space research conducted by the United States. Some seventy foreign countries and jurisdictions participate with the United States in joint satellite projects. Such joint projects include the contributing of experiments to satellites, the launching of sounding rockets, the sharing of ground-based support facilities for scientific satellites, joint participation in worldwide tracking networks, and visitor exchanges in technical training programs. Many experiments, including complete satellites, are built by other nations with the United States providing the launch vehicles, launch facilities, and other support. In addition, experiments from other nations are sometimes selected in competition with domestic proposals for inclusion on NASA satellites. An excellent example of the launching of an international satellite by NASA was the British-built ARIELS satellite, the world's first international satellite. It was launched on April 26, 1962 by NASA. It carried experiments built in the United Kingdom. This satellite has provided information on the variation of cosmic rays with Earth latitude and the intensity of radiations in the Van Allen Radiation Regions.

In addition, the United States has provided services to the following nations in their satellite programs:

Canada — launch, tracking, and data acquisition for the Alouette satellite (used to measure electron density of the ionosphere) and the ISIS (International Satellite for Ionospheric Studies); France — tracking and data acquisition for FR-I (measurement of electric and magnetic field components of very low-frequency radio emission); Italy — training, launch, tracking and data acquisition of the San Marco satellite (to determine air density by measuring satellite drag).

The United States has also participated in sounding rocket programs with Argentina, Australia, India, Japan, New Zealand, Norway, Denmark, Pakistan, and Sweden.

Other cooperative ventures include participation in international organizations dedicated to the development of space sciences or the utilization of space technology. Typical organizations are:

(1) The International Telecommunications Satellite Consortium (Intelsat), a group of over fifty cooperating nations, has assumed a major role in the establishment of an international commercial communication satellite system to enable participating nations to respond to their communication needs.

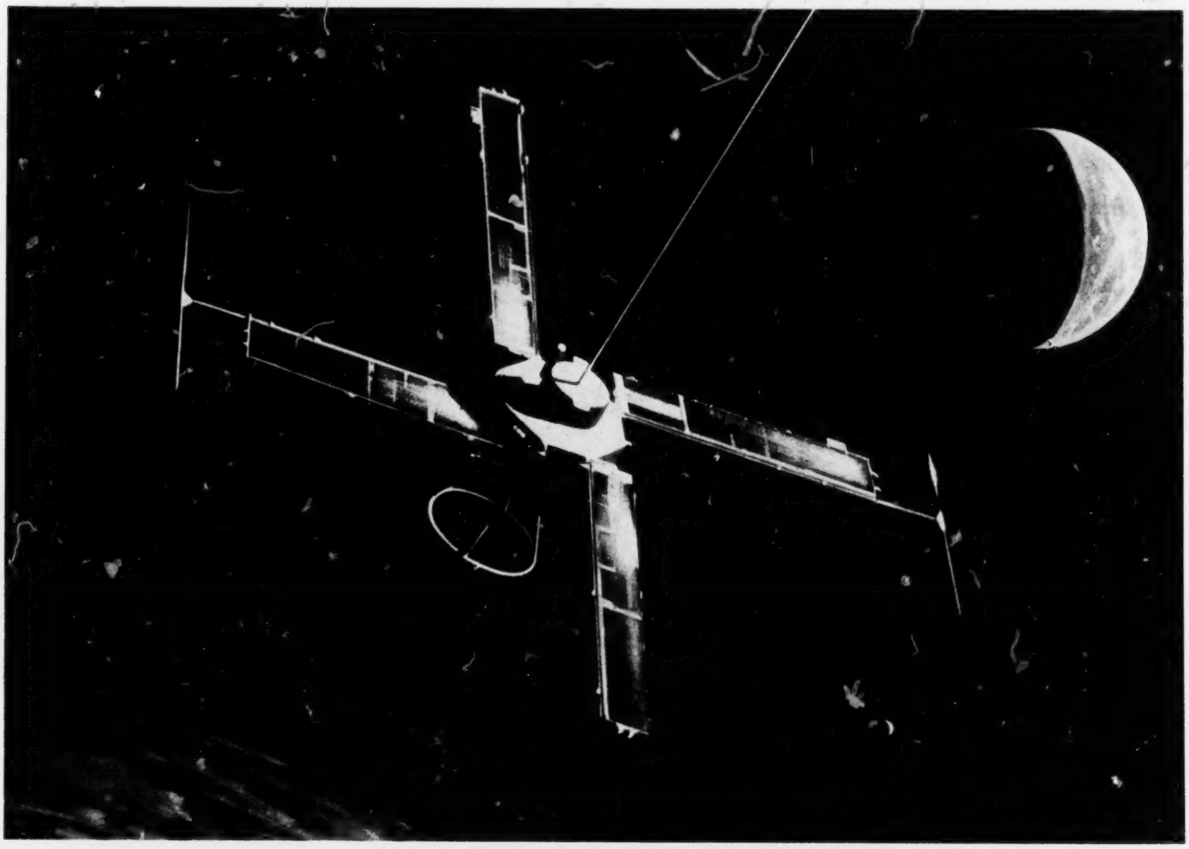
(2) The European Space Research Organization (ESRO) was set up by a group of nations to build, launch and monitor satellites and sounding rockets. On March 28, 1966 this organization and the United States agreed to the establishment of a satellite telemetry-telecommand station near Fairbanks, Alaska, (the first foreign space station on United States soil).

(3) The European Launcher Development Organization (ELDO) established an initial program to design, develop and construct a space vehicle launcher weighing over 100 tons. The organization also plans to study the problems of accurately placing satellites in predetermined orbits and to determine the dynamic behavior of satellites during the propulsion phase and after entry into orbit.

There are other examples of bilateral and multilateral organizations that are striving for the betterment of particular areas of interest. Indeed, these have accomplished a great deal in attempting to solve the technological problems of the Space Age. Nations can readily help one another with mutual difficulties when a cooperative spirit prevails. It is not the lack of specific organizations but rather the reluctance of nations to bind together in a coordinating agency that may handicap and delay international applications of space technology.

Many examples can be provided where international cooperation and coordination in the future will be vital to the betterment of civilization. One such future program is the establishment of a worldwide satellite communication system. Although a limited approach to such an international communication system is now in existence, the purpose of the current system is not designed to bring communications to those parts of the world that have the greatest need. A communication satellite has the capability to provide educational television over large remote land masses, such as South America and Africa. In such a system the satellite acts as the classroom instructor, with students gathered at every point where a receiver can be established. Not only would this system help to solve the critical problem of teacher shortages, but excellent instruction could be maintained on long-term basis. Communication satellites might hasten the creation of a universal language so that all people of the world could monitor the same broadcasts.

203



Another area of international interest is navigation. On July 29, 1967, Vice-President Hubert Humphrey announced Presidential approval of a recommendation to release the Navy's Navigation Satellite System (see Chapter Fifteen) for use by civilian ships. Commercial manufacture of the shipboard receivers would make mass distribution possible. Much interest has been expressed in the United States for the use of such a system by the oceanographic community, off-shore oil exploration companies, and other segments of industry. Minor modifications of this system would permit use of these navigation aids by the ships of other nations. Indeed, the potential of the navigation satellite is within sight to assure accurate navigation anywhere on Earth. Other aspects of an international navigation satellite system might involve a 24-hour all-weather notification service including commercial air traffic control, search and rescue assistance, iceberg warning, and Super Service Transport (SST) flight advisories.

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Use of international satellites would extend world meteorology programs. Details of existing meteorological satellite systems were covered in Chapter Fourteen. Not only can future meteorology satellites offer the world complete and accurate weather forecasting, but this increased knowledge may lead to weather control or modification. Weather observations to enhance forecasting is well appreciated today, but use of increased knowledge for weather control or weather planning may be the key to better balance of world food production.

A realistic appraisal of the United Nations Space Treaty clearly indicates other areas for further international agreement. Negotiations are necessary concerning the liability problems that surround space ventures. Basic questions of what types of liability problems will arise must be explored. Acceptance of these responsibilities by each nation must be formalized by treaty. Although the current treaty expresses the willingness of nations to preserve the environment of space as a peaceful area for exploration, the necessary controls and enforcement measures have yet to be documented. If man can truly cooperate in the arena of space, there exists the probability that this cooperation may be reflected in many of the problems that face man on Earth. The rise of the underdeveloped nations with their exploding populations poses challenges which may be best solved in terms of advanced technology. The space sciences can assist in these problems if international conditions will permit discussions and decision making on a non-belligerent basis. If, however, world conditions are filled with wars and the rumors of wars then space science, as all science does in some respect, will become the newest tool for the conduct of wars by technical nations.

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RECONNAISSANCE
COMMUNICATIONS
NAVIGATION
METEOROLOGY

The Navy is aware of the implications of future space technology on naval operations. It has studied the ways in which Naval forces and combat operations will be affected by astronautic systems. It has established definite, formal operational requirements in the areas of communications, meteorology, navigation, and surveillance.

Many technical problems remain as challenges to Naval planners, for example, (1) the development of practical shipboard antennas for use with satellites, and (2) the need for weather readouts on a more frequent basis. Optimally, the antennas should not overburden the ship by weight or restrict its maneuverability by requirements for steady steaming on course during satellite pickup operations, and weather should be available over areas of interest on a 3-hour presentation schedule. Other problems are slowly being solved in the areas of reliability, maintenance, and adequately trained personnel. The fleet will derive more benefits as the Navy Astronautics Program continues the integration and coordination of space system development within the overall development plans of the Navy. This Navy Astronautics Program is guided by the following principles that prescribe the current and future Navy role in space:

a. To influence, wherever possible, the design of DOD or NASA satellite systems to insure that Navy requirements are met;

b. To design, develop, and operate satellite systems uniquely supporting Navy requirements, or requiring unique naval capabilities;

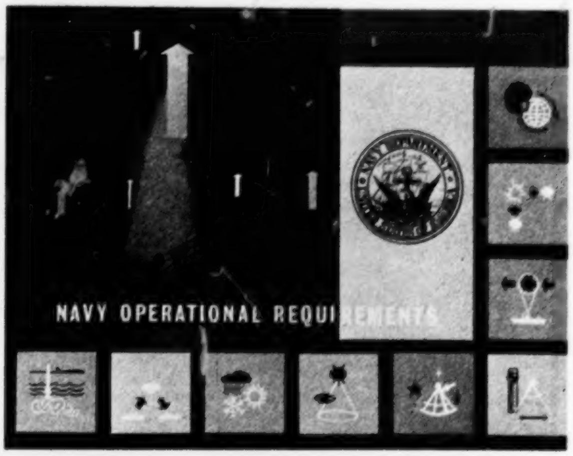
c. To make available competent naval officers to other Services or agencies to insure the most effective applications of naval technology to national objectives where and when needed;

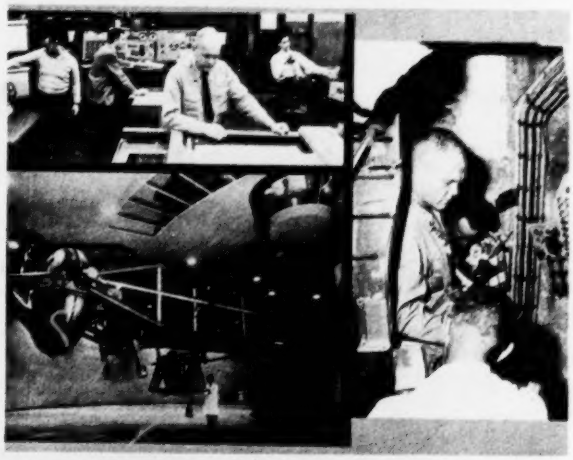
d. To maintain an active astronautics research program to prevent naval obsolescence by advances in space technology;

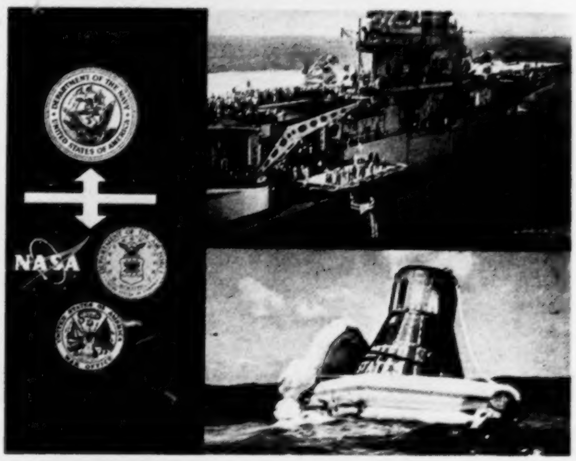
e. To establish and maintain an educational and training program responsive to advances in space technology;

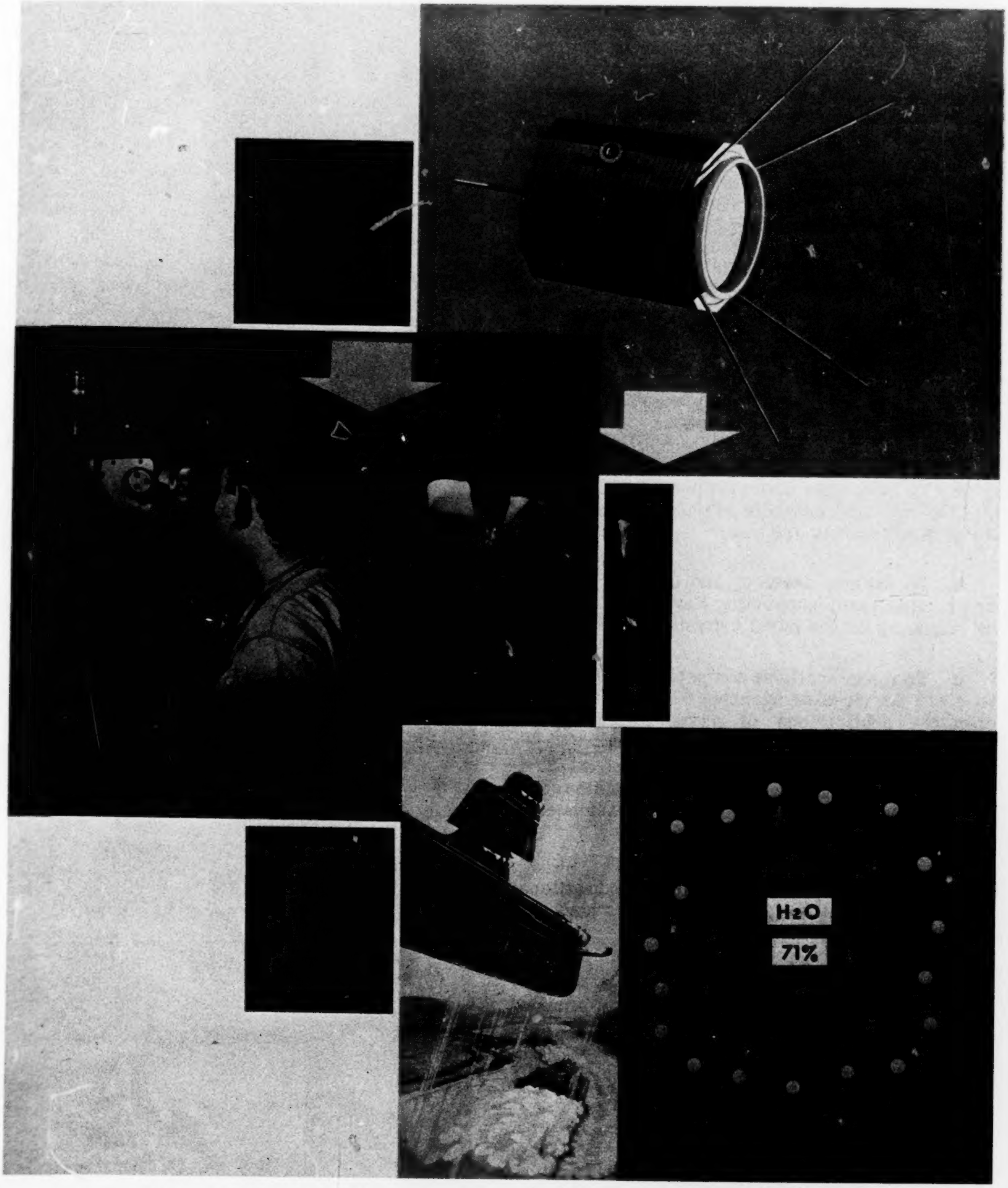
f. To participate actively with the National Aeronautics and Space Administration manned space flight program to insure a constant awareness of the potential of manned space flight as it may affect naval operations.

Such a program cooperatively carried out by scientists, engineers, and naval personnel will provide the necessary systems that the Navy will need to fulfill its basic missions in the space age.









207

APPENDIX I

CONDENSED LISTING OF SIGNIFICANT SPACE LAUNCHES

Name	Country	Date			Remarks
SPUTNIK 1	USSR	4	October	1957	First artificial satellite
SPUTNIK 2	USSR	3	November	1957	Carried dog Laika
EXPLORER 1	U.S.	31	January	1958	First U.S. satellite - discovered Van Allen Radiation Belt
SCORE	U.S.	18	December	1958	First communication satellite
LUNA 2	USSR	12	September	1959	First probe to hit Moon
LUNA 3	USSR	4	October	1959	First photos of far side of Moon
TIROS 1	U.S.	1	April	1960	First meteorological satellite
TRANSIT 1B	U.S.	13	April	1960	First navigational satellite
TRANSIT 2A SOLRAD 1	U.S.	22	June	1960	First dual launch - U.S. Navy
ECHO 1	U.S.	12	August	1960	First passive communication satellite.
DISCOVERER 14	U.S.	18	August	1960	First mid-air capsule recovery
COURIER 1B	U.S.	4	October	1960	First active repeater Comsat
VOSTOK 1	USSR	12	April	1961	First manned space flight
TRANSIT 4A INJUN 1 SOLRAD 3	U.S.	29	June	1961	First nuclear power supply (SAMOS 3) First triple launch - U.S. Navy
OSCAR 1	U.S.	12	December	1961	First amateur radio operators satellite
MERCURY (Friendship 7)	U.S.	20	February	1962	First U.S. manned orbital space flight, John H. Glenn
ARIEL 1	U.S./U.K.	26	April	1962	Joint US/UK ionospheric
MERCURY-ATLAS 7	U.S.	24	May	1962	AURORA 7 - Scott Carpenter
TELSTAR 1	U.S.	10	July	1962	Active repeater Comsat
VOSTOK 3	USSR	11	August	1962	A. Nikolayev - 64 orbits } group
VOSTOK 4	USSR	12	August	1962	P. Popovich - 48 orbits } flight
ALOUETTE	US/Canada	28	September	1962	First Canadian satellite
MERCURY-ATLAS 8	U.S.	3	October	1962	SIGMA 7, W. Schirra, 6 orbits

Name	Country	Date	Remarks
ANNA 1B	U.S.	31 October 1962	Geodetic satellite
None INJUN 3 None None None	U.S.	12 December 1962	First five satellite launch
MERCURY-ATLAS	U.S.	15 May 1963	FAITH 7, L.G. Cooper, 22 orbits
VOSTOK 5	USSR	14 June 1963	V. Bykovsky - 81 orbits group flight
VOSTOK 6	USSR	16 June 1963	V. Tereshkova - 48 orbits
SYNCOM 2	U.S.	26 July 1963	First successful synchronous comsat.
POLYOT 1	USSR	1 November 1963	First spacecraft with extensive maneuver capability (Soviet claim)
TRANSIT 5BN	U.S.	5 December 1963	SNAP 9A nuclear power supply
TIROS 8	U.S.	21 December 1963	Contained automatic picture transmission T.V. camera. Returned weather pictures of Earth.
SECOR 1	U.S.	11 January 1964	1 of 5 satellites in multiple launch Army geodetic satellite.
ELECTRON 1 ELECTRON 2	USSR	30 January 1964	To study radiation belts: first Soviet dual launch.
COSMOS 38 COSMOS 39 COSMOS 40	USSR	18 August 1964	First Soviet triple launch.
SYNCOM 3	U.S.	19 August 1964	First geostationary synchronous communication satellite.
NIMBUS 1	U.S.	28 August 1964	First satellite in NIMBUS meteorological satellite program.
VOSKHOD 1	USSR	12 October 1964	First 3-man crew, V. Komarov, K. Feokistov, B. Yegorov: 16 orbits.
MARINER 4	U.S.	28 November 1964	Returned 21 photos of Mars
SAN MARCO 1	US/Italy	15 December 1964	First Italian satellite
VOSKHOD 2	USSR	18 March 1965	A. Leonov spent ten minutes outside capsule
GEMINI 3	U.S.	23 March 1965	V. Grissom and J. Young, first manned orbital maneuvers, 3 orbits
EARLY BIRD	U.S.	6 April 1965	Commercial communication service initiated June 28, 1965
MOLNIYA 1A	USSR	23 April 1965	First Soviet comsat

Appendix I — SIGNIFICANT SPACE LAUNCHES

Name	Country	Date	Remarks
GEMINI 4	U.S.	3 June 1965	J. McDivitt and E. H. White. White performed 21 minute EVA experiment, 66 orbits.
COSMOS 71	USSR	16 July 1965	First Soviet five-satellite launch
COSMOS 72			
COSMOS 73			
COSMOS 74			
COSMOS 75			
PROTON 1	USSR	16 July 1965	Heaviest Soviet payload. "Physics Lab" according to Soviet releases.
ZOND 3	USSR	18 July 1965	Transmitted pictures taken of Moon during Lunar flyby.
GEMINI 5	U.S.	21 August 1965	First extended U.S. manned space flight, L.G. Cooper and C. Conrad landed after 128 orbits.
MOLNIYA 1B	USSR	14 October 1965	Second Soviet comsat USSR/France communication link.
VENUS 2	USSR	12 November 1965	Passed Venus February 27, 1966 no data
VENUS 3	USSR	16 November 1965	Impacted on Venus - no data
A 1	France	26 November 1965	First French satellite
GEMINI 7	U.S.	4 December 1965	F. Borman and J. Lovell, 220 orbits, served as rendezvous target for Gemini 6.
GEMINI 6	U.S.	15 December 1965	W. Schirra and T. Stafford within one foot of Gemini 7, 17 orbits.
LUNA 9	USSR	31 January 1966	First photos from surface of the Moon.
ESSA 1	U.S.	3 February 1966	First operational metsat
GEMINI 8	U.S.	16 March 1966	N. Armstrong and D. Scott initial docking test, landed after 6.5 orbits due to short circuit.
LUNA 10	USSR	31 March 1966	First Lunar orbiter
GEMINI 9	U.S.	3 June 1966	T. Stafford and E. Cernan Rendezvous and EVA tests performed, 47 orbits.
GGTS 1	U.S.	16 June 1966	Gravity gradient test satellite
IDCSP 1			7 initial defense communication satellites.
IDCSP 2			
IDCSP 3			
IDCSP 4			
IDCSP 5			
IDCSP 6			
IDCSP 7			

Name	Country	Date	Remarks
COSMOS 122	USSR	25 June 1966	Metsat launch seen by General De Gaulle
GEMINI 10	U.S.	18 July 1966	Rendezvoused with Gemini 8 and 10 targets, J. Young and M. Collins, 43 orbits.
LUNAR ORBITER 1	U.S.	12 September 1966	First photos of Moon from Moon orbit.
GEMINI 11	U.S.	12 September 1966	C. Conrad and R. Gordon performed initial first docking, 47 orbits.
LAMBDA 4S 1	Japan	26 September 1966	Failed to orbit: first attempt to launch Japanese satellite.
GEMINI 12	U.S.	11 November 1966	J. Lovell and E. Aldrin successful EVA tests, 63 orbits.
ATS-B F1	U.S.	6 December 1966	First comsat to test air-to-ground and air-to-air communication via satellite.
INTELSAT II-F2	U.S.	11 January 1967	Transpacific communication service initiated January 1, 1967.
IDCSP 8 9 10 11 12 13 14 15	U.S.	18 January 1967	In orbit: initial defense communication satellite.
D 1C	France	8 February 1967	Geodetic satellite
D 1D	France	15 February 1967	Duplicate of D 1C
COSMOS 144	USSR	28 February 1967	Metsat: similar to Cosmos 122
INTELSAT II-F3	U.S.	22 March 1967	Completes Intelsat II communication system
IDCSP 16 IDCSP 17 IDCSP 18 IDCSP 19	U.S.	1 July 1967	
DODGE DATS			DOD gravity experiment despun antenna test satellite
LES-5			First comsat to operate solely in UHF band first to have an all solid-state UHF band transmitter first operating at UHF to transmit circularly polarized signals.

APPENDIX II

GLOSSARY

Ablation.—The removal of surface material from a body by vaporization, melting, chipping, or other erosive process; specifically, the intentional removal of material from a nose cone or spacecraft during high-speed movement through a planetary atmosphere to cool the underlying structure.

Acquisition.—1. The process of locating the orbit of a satellite or trajectory of a space probe so that tracking or telemetry data can be gathered. 2. The process of pointing an antenna or telescope so that it is properly oriented to allow gathering of tracking or telemetry data from a satellite or space probe.

Aerospace.—1. Of or pertaining to both the Earth's atmosphere and space, as in aerospace industries. 2. Earth's envelope of air and space above it; the two considered as a single realm for activity in the flight of air vehicles and in the launching, guidance and control of ballistic missiles, Earth satellites, dirigible space vehicles, and the like.

(Aerospace in sense 2 is used primarily by the U.S. Air Force.)

The term aerospace first appeared in print in the Interim Glossary Aerospace Terms (edited by Woodford Agee Heflin) published in February 1958 at the Air University, Maxwell Air Force Base, Ala.

Alpha Decay.—The radioactive transformation of a nuclide by alpha-particle emission. Also called alpha disintegration.

The decay product is the nuclide having a mass number four units smaller and an atomic number two units smaller than the original nuclide.

Alpha Particle.—A positively charged particle emitted from the nuclei of certain atoms during radioactive disintegration. The alpha particle has an atomic weight of 4 and a positive charge equal in magnitude to 2 electronic charges; hence it is essentially a helium nucleus (helium atom stripped of its two planetary electrons). Compare beta particle, gamma ray.

American Ephemeris and Nautical Almanac.—An annual publication of the U.S. Naval Observatory, containing elaborate tables of the predicted positions of various celestial bodies and other data of use to astronomers and navigators.

Beginning with the editions for 1960, The American Ephemeris and Nautical Almanac issued by the Nautical Almanac Office, United States Naval Observatory, and The Astronomical Ephemeris issued by H.M. Nautical Almanac Office, Royal Greenwich Observatory, were unified. With the exception of a few introductory pages, the two publications are identical; they are printed separately in the two countries, from reproducible material prepared partly in the United States of America and partly in the United Kingdom.

Angstrom.—A unit of length, used chiefly in expressing short wavelengths. It equals 10^{-10} meters or 10^{-8} centimeters.

Aphelion.—That point in a solar orbit which is most distant from the Sun. The point nearest the Sun is called perihelion.

Apogee.—1. That point in a geocentric orbit which is most distant from the Earth. That orbital point nearest the Earth is called perigee.

By extension, apogee and perigee are also used in reference to orbits about other planets and natural satellites.

2. Of a satellite or rocket: to reach its apogee (sense 1), as in the Vanguard apogees at 2,560 miles.

Argument.—In astronomy, an angle or arc, as in argument of perigee.

Argument of Perigee.—In celestial mechanics, the angle or arc, as seen from a focus of an elliptical orbit, from the ascending node to the closest approach of the orbiting body to the focus. The angle is measured in the orbital plane in the direction of motion of the orbiting body.

Ascending Node. — That point at which a plant, planetoid, or comet crosses to the north side of the ecliptic; that point at which a satellite crosses to the north side of the equatorial plane of its primary. Also called northbound node. The opposite is descending node or southbound node.

Asteroid.—One of the many small celestial bodies revolving around the Sun, most of the orbits being between those of Mars and Jupiter. Also called planetoid, minor planet.

The term minor planet is preferred by many astronomers but asteroid continues to be used in astronomical literature, especially attributively, as in asteroid belt.

All asteroids with determined orbits (except for a few discovered during World War II) are numbered for identification in the order of their discovery. The Ephemerides of the Minor Planets published by the USSR Academy of Sciences lists all numbered asteroids, data concerning them, and their predicted positions. The daily positions of the first four minor planets are tabulated in the American Ephemeris and Nautical Almanac. Orbits have been determined for approximately 1700 asteroids.

Asteroids have names as well as numbers. The names are usually feminine but masculine names have been used for asteroids closer to or farther away from the Sun than the majority. The first asteroid to be given a masculine name, Eros (443) was the first to be discovered inside the orbit of Mars. The Trojan asteroids, named for heroes of the Trojan war, are in the orbit of Jupiter.

Astrodynamics.—The practical application of celestial mechanics, astroballistics, propulsion theory, and allied fields to the problem of planning and directing the trajectories of space vehicles.

Astrodynamics is sometimes used as a synoym for celestial mechanics. This usage should be discouraged.

Astronaut. — 1. A person who rides in a space vehicle. 2. Specifically, one of the test pilots selected to participate in Project Mercury, Project Gemini, Project Apollo, or any other United States program for manned space flight.

Astronautics.—1. The art, skill, or activity of operating spacecraft. 2. In a broader sense the science of space flight.

Astronomical Unit. (abbr AU).—1. A unit of length, usually defined as the distance from the Earth to the Sun, 149,599,000 kilometers.

This value for the AU was derived from radar observations of the distance of Venus. The value given in astronomical ephemerides, 149,500,000 kilometers, was derived from observations of the minor planet Eros.

2. The unit of distance in terms of which, in the Kepler Third Law, $n^2a^3 = k^2\ (1 + m)$, the semimajor axis $\underline{a}$ of an elliptical orbit must be expressed in order that the numerical value of the Gaussian constant $\underline{k}$ may be exactly 0.01720209895 when the unit of time is the ephemeris day.

In astronomical units, the mean distance of the Earth from the Sun, calculated by the Kepler law from the observed mean motion $\underline{n}$ and adopted mass $\underline{m}$, is 1.00000003.

Atmosphere.—1. The envelope of air surrounding the Earth; also the body of gases surrounding or comprising any planet or other celestial body.

Atmospheric Entry.— The penetration of any object from outer space; specifically, the penetration of the Earth's atmosphere by a manned or unmanned capsule or spacecraft.

Atomic Clock.— A timekeeping device controlled by the frequency of the natural vibrations of certain atoms.

Atomic Mass.— The mass of a neutral atom of a nuclide usually expressed in atomic mass units.

The atomic mass unit, amu, is exactly one-twelfth of the mass of a neutral atom of the most abundant isotope of carbon, $C^{12} = 12.0000$.

Attenuation.—Reduction in intensity.

Attitude.— The position or orientation of an aircraft, spacecraft, etc., either in motion or at rest, as determined by the relationship between its axes and some reference line or plane or some fixed system of reference axes.

Aurora.— The sporadic radiant emission from the upper atmosphere over middle and high latitudes. It is believed to be due primarily to the emission from nitrogen, atomic NI and NII, molecular N_2, and ionic N_2 +; atomic oxygen OI and OII); atomic sodium (NaI); the hydroxyl radical (OH); and hydrogen.

Auroral Zone.— A roughly circular band around either geomagnetic pole above which there is a maximum of auroral activity. It lies about 10° to 15° of geomagnetic latitude from the geomagnetic poles.

The auroral zone broadens and extends equatorward during intense auroral displays.

The northern auroral is centered along a line passing Point Barrow, Alaska, through the lower half of Hudson Bay, slightly off the southern tip of Greenland, through Iceland, northern Norway and Northern Siberia. Along this line auroras are seen on an average of 240 nights a year. The frequency of auroras falls off both to the north and to the south of this line but more rapidly to the south. The most severe blackouts occur in the auroral zone.

B

Ballistic Body. — A body free to move behave, and be modified in appearance, contour, or texture by ambient conditions, substances, or forces, as by the pressure of gases in a gun, by rifling in a barrel, by gravity, by temperatures, or by air particles.

A rocket with a self-contained propulsion unit is not considered a ballistic body during the period of its guidance or propulsion.

Balloon-Type Rocket.— A liquid-fuel rocket, such as Atlas, that requires the pressure of its propellants (or other gases) within it to give it structural integrity.

Ballute. — A cross between a balloon and a parachute, used to brake the free fall of sounding rockets.

Bandwidth.— 1. In an antenna, the range of frequencies within which its performance, in respect to some characteristic, conforms to a specified standard. 2. In a wave, the least frequency interval outside of which the power spectrum of a time-varying quantity is everywhere less than some specified fraction of its value at a reference frequency. 3. The number of cycles per second between the limits of a frequency band.

Sense 2 permits the spectrum to be less than the specified fraction within the interval. Unless otherwise stated, the reference frequency is that at which the spectrum has its maximum value.

4. In information theory, the information carrying capacity of a communications channel.

Bar.— A unit of pressure equal to 10^6 dyne per square centimeter (10^6 barye), 1000 millibars, 29.53 inches of mercury.

Barn (abbr b).— A unit of area for measuring a nuclear cross section. One barn equals 10^{-24} square centimeter.

Beam Width.— A measure of the concentration of power of a directional antenna. It is the angle in degrees subtended at the antenna by arbitrary power-level points across the axis of the beam. This power level is usually the point where the power density is one-half that which is present in the axis of the beam at the same distance from the antenna (half-power points). Also called beam angle.

The beam width of a radar determines the minimum angular separation which two targets can have and still be resolved. Roughly speaking, two targets at the same range whose angular separations at the radar antenna exceeds one-half of the beam width between half-power points will be resolved or distinguishable as two individual targets. The smaller the beam width, the greater the angular resolving power. Beam width may be at different locations through the axis depending upon the shape of the antenna reflector.

Beat Frequency.— The frequency obtained when two simple harmonic quantities of different frequencies f_1 and f_2^2 are superimposed. The beat frequency equals f_1 -f_2.

Beta Disintegration.— Beta decay.

Beta Ray, β-Ray.—A steam of beta particles.

Binary. — 1. Involving the integer two (2). 2. = binary cell. 3. = binary star.

Binary Code. — A code composed of a combination of entities each of which can assume one of two possible states. Each entity must be identifiable in time or space.

Binding Energy.—1. The force which holds molecules, atoms, or atomic particles together; specifically, the force which holds an atomic nucleus together. 2. The energy required to break chemical, atomic, or molecular bonds.

Bioastronautics. — The study of biological, behavioral, and medical problems pertaining to astronautics. This includes systems functioning in the environments expected to be found in space, and the conditions on celestial bodies other than on Earth.

Boiling Point.—(abbr bp). The temperature at which equilibrium vapor pressure between a liquid and its vapor is equal to the external pressure on the liquid.

Boiloff.— The vaporization of a liquid, such as liquid oxygen or liquid hydrogen, as its temperature reaches its boiling point under conditions of exposure, as in the tank of a rocket being readied for launch.

Boost.—1. Additional power, pressure, or force supplied by a booster, as hydraulic boost, or extra propulsion given a flying vehicle during lift-off, climb, or other part of its flight as with a booster engine. 2. Boost pressure. 3. To supercharge. 4. To launch or to push along during a portion of flight, as to boost a ramjet to flight speed by means of a rocket, or a rocket boosted to altitude with another rocket.

Booster.—1. Short for booster engine or booster rocket. 2. = launch vehicle.

Booster Engine.—An engine, especially a booster rocket, that adds its thrust to the thrust of the sustainer engine.

Booster Rocket.—1. A rocket motor, either solid or liquid, that assists the normal propulsive system or sustainer engine of a rocket or aeronautical vehicle in some phase of its flight. 2. A rocket used to set a vehicle in motion before another engine takes over. In sense 2 the term launch vehicle is preferred.

Braking Ellipses.—A series of ellipses, decreasing in size due to aerodynamic drag, followed by a spacecraft in entering a planetary atmosphere.

In theory, this maneuver will allow a spacecraft to dissipate the heat generated in entry without burning up.

Bremsstrahlung Effect.—The emission of electromagnetic radiation as a consequence of the acceleration of charged elementary particles, such as electrons, under the influence of the attractive or repulsive force fields of atomic nuclei near which the charged particle moves.

In cosmic-ray shower production, bremsstrahlung effects give rise to emission of radiation. The bremsstrahlung effect is merely one instance of the general rule that electromagnetic radiation is emitted only when electric charges undergo acceleration.

C

Calorimeter. — An instrument designed to measure heat evolved or absorbed. Calorimeters are used in some pyrheliometers.

Capsule.—1. A boxlike component or unit, often sealed. See aneroid. 2. A small, sealed, pressurized cabin with an internal environment which will support life in a man or animal during extremely high altitude flight, space flight, or emergency escape. See ejection capsule.

The term spacecraft is preferred to capsule for any man-carrying vehicle.

3. A container carried on a rocket or spacecraft, as an instrument capsule holding instruments intended to be recovered after a flight.

Cardiovascular.—Pertaining to the heart and the blood vessels.

Cartesian Coordinates.—A coordinate system in which the locations of points in space are expressed by reference to three planes, called coordinate planes, no two of which are parallel.

The three planes intersect in three straight lines, called coordinate axes. The coordinate planes and coordinate axes intersect in a common point, called the origin. From any point P in space three straight lines may be drawn, each of which is parallel to one of the three coordinate planes. If A. B. C. denote these points of intersection, the Cartesian co-

215

ordinates of P are the distances PA, PB, and PC. If the coordinate axes are mutually perpendicular, the coordinate system is rectangular; otherwise, oblique.

Cathode.—In an electron tube, an electrode through which a primary stream of electrons enters the interelectrode space.

Celestial Body.—Any aggregation of matter in space constituting a unit for astronomical study, as the Sun, Moon, a planet, comet, star, nebular, etc. Also called heavenly body.

Celestial Coordinates.—Any set of coordinates used to define a point on the celestial sphere. The horizon, celestial equator, ecliptic, and galactic systems of celestial coordinates are based on the celestial horizon, celestial equator, ecliptic, and galactic equator, respectively, as the primary great circle.

Celestial Equator.—The primary great circle of the celestial sphere in the equatorial system, everywhere 90° from the celestial poles; the intersection of the extended plane of the equator and the celestial sphere. Also called equinoctial.

Celestial Latitude.—Angular distance north or south of the ecliptic; the arc of a circle of latitude between the ecliptic and a point on the celestial sphere, measured northward or southward from the ecliptic through 90°, and labeled N or S to indicate the direction of measurement. See ecliptic system of coordinates.

Celestial Line of Position.—A line of position determined by observation of one (or more) celestial bodies.

Celestial Longitude.—Angular distance east of the vernal equinox, along the ecliptic; the arc of the ecliptic or the angle at the ecliptic pole between the circle of latitude of the vernal equinox and the circle of latitude of a point on the celestial sphere, measured eastward from the circle of latitude of the vernal equinox, through 360°.

Celestial Mechanics.—The study of the theory of the motions of celestial bodies under the influence of gravitational fields. See Gravitation.

Celestial Meridian.—A great circle of the celestial sphere, through the celestial poles and the zenith.

The expression usually refers to the upper branch, that half of the great circle from pole to pole which passes through the zenith; the other half being the lower branch. The celestial meridian coincides with the hour circle through the zenith and the vertical circle through the elevated pole.

Celestial Navigation.—The process of directing a craft from one point to another by reference to celestial bodies of known coordinates.

Celestial navigation usually refers to the process as accomplished by a human operator. The same process accomplished automatically by a machine is usually termed celestial guidance or sometimes automatic celestial navigation.

Celestial Observation.—In navigation, the measurement of the altitude of a celestial body, or the measurement of azimuth, or measurement of both altitude and azimuth. Also called sight.

The expression may also be applied to the data obtained by such measurement.

Celestial Pole.—Either of the two points of intersection of the celestial sphere and the extended axis of the Earth, labeled N or S to indicate whether the north celestial pole or the south celestial pole.

Celestial Sphere.—An imaginary sphere of infinite radius concentric with the Earth, on which all celestial bodies except the Earth are assumed to be projected.

Celestial Triangle.—A spherical triangle on the celestial sphere, especially the navigational triangle.

Centrifugal Force.—The apparent force in a rotating system, deflecting masses radially outward from the axis of rotation, with magnitude per unit mass $w^2 R$, where $\underline{w}$ is the angular speed of rotation; and R is the radius of curvature of the path. This magnitude may also be written as V^2/R, in terms of the linear speed V. This force (per unit mass) is equal and opposite to the centripetal acceleration. Also called centrifugal acceleration.

The centrifugal force on the Earth and atmosphere due to rotation about the Earth's axis is incorporated with the field of gravitation to form the field of gravity.

Centrifuge.—Specifically, a large motor-driven apparatus with a long arm at the end of which human and animal subjects or equipment can be revolved and rotated at various speeds to simulate (very closely) the (prolonged) accelerations encountered in high-performance aircraft, rockets, and spacecraft. Sometimes called astronautic centrifuge.

Centripetal Acceleration.—The acceleration on a particle moving in a curved path, directed toward the instantaneous center of curvature of the path, with magnitude v^2/R, where $\underline{v}$ is the speed of the particle and R the radius of curvature of the path. This acceleration is equal and opposite to the centrifugal force per unit mass.

Chain Reaction.—A reaction in which one of the agents necessary to the reaction is itself produced by the reaction, thus causing like reactions.

In the neutron-fission chain reaction, a neutron striking a fissionable atom causes a fission releasing neutrons which cause other fissions.

Circular Velocity.— At any specific distance from the primary, the orbital velocity required to maintain a constant-radius orbit.

Circumlunar.—Around the Moon, generally applied to trajectories.

Cislunar.—(Latin cis, on this side). Of or pertaining to phenomena, projects, or activity in the space between the Earth and Moon, or between the Earth and the Moon's orbit.

Closed Ecological System.—A system that provides for the maintenance of life in an isolated living chamber through complete reutilization of the material available, in particular, by means of a cycle wherein exhaled carbon dioxide, urine, and other waste matter are converted chemically or by photosynthesis into oxygen, water, and food.

Combustion Instability.—Unsteadiness or abnormality in the combustion of fuel, as may occur, e.g., in a rocket engine.

Comet.—A luminous member of the solar system composed of a head, or coma, and often with a spectacular gaseous trail extending a great distance from the head. The orbits of comets are highly elliptical.

Command Control.—A system whereby functions are performed as the result of a transmitted signal.

Command Destruct.—A command control system that destroys a flightborne test rocket, actuated on command of the range safety officer whenever the rocket performance indicates a safety hazard.

Command Guidance.—The guidance of a spacecraft or rocket by means of electronic signals sent to receiving devices in the vehicle.

Communications Satellite.—A satellite designed to reflect or relay electromagnetic signals used for communication.

Conic.—1. A curve formed by the intersection of a plane and a right circular cone. Originally called conic section.

The conic sections are the ellipse, the parabola, and the hyperbola, curves that are used to describe the paths of bodies moving in space.

The circle is a special case of the ellipse, an ellipse with an eccentricity of zero.

The conic is the locus of all points the ratio of whose distances from a fixed point, called the focus, and a fixed line, called the directrix, is constant.

2. In reference to satellite orbital parameters, without consideration of the perturbing effects of the actual shape or distribution of mass of the primary.

Thus, conic perigee is the perigee the satellite would have if all the mass of the primary were concentrated at its center.

Conservation of Angular Momentum.—The principle that absolute angular momentum is a property which cannot be created or destroyed but can only be transferred from one physical system to another through the agency of a net torque on the system. As a consequence, the absolute angular momentum of an isolated physical system remains constant.

The principle of conservation of an isolated momentum can be derived from the Newton second law of motion.

Conservation of Energy.—The principle that the total energy of an isolated system remains constant if no interconversion of mass and energy takes place.

Conservation of Mass.—The principle in Newtonian mechanics which states that mass cannot be created or destroyed but only transferred from one volume to another.

Conservation of Momentum.— The principle that in the absence of forces absolute momentum is a property which cannot be created or destroyed. See Newton laws of motion.

Cosmic. — Of or pertaining to the universe, especially that part of it outside the Earth's atmosphere. Used by the USSR as equivalent to space, as in cosmic rocket, cosmic ship.

Cosmic Dust.—Finely divided solid matter with particle sizes smaller than a micrometorite, thus with diameters much smaller than a millimeter, moving in interplanetary space.

Cosmic dust in the solar system is thought to be concentrated in the plane of the ecliptic, thus causing the zodiacal light.

Cosmic Rays.—The aggregate of extremely high-energy subatomic particles which travel the solar system and bombard the Earth from all directions. Cosmic-ray primaries seem to be mostly protons, hydrogen nuclei, but also contain heavier nuclei. On colliding with atmospheric particles they produce many different kinds of lower energy secondary cosmic radiation.

Cosmic rays thought to originate outside the solar system are called galactic cosmic rays. Those thought to originate in the Sun are called solar cosmic rays.

In the Earth's atmosphere, the maximum flux of cosmic rays both primary and secondary, is at an altitude of 20 km and below this the absorption of the atmosphere reduces the flux, though the rays are still readily detectable at sea level. Intensity of cosmic-ray showers has also been observed to vary with latitude, being more intense at the poles.

Critical Mass. — The amount of concentrated fissionable material that can just support a self-sustaining fission reaction.

D

Data-Acquisition Station.—A ground station at which various functions to control satellite operations and to obtain data from the satellite are performed.

Data Link.—Any communications channel or circuit used to transmit data from a sensor to a computer, a readout device, or a storage device.

Data Processing. — Application of procedures, mechanical, electrical, computational, or other, whereby data are changed from one form into another.

Data Reduction. — Transformation of observed values into useful, ordered, or simplified information.

Datum.—Any numerical or geometrical quantity or set of such quantities which can serve as a reference or a base for measurement of other quantities.

For a group of statistical references, the plural form is data; as geogeographic data for a list of latitudes and longitudes. Where the concept is geometrical the plural form is datums; as in two geodetic datums have been used.

Datum Line.—Any line which can serve as a reference or base for the measurement or other quantities.

Datum Plane.—A plane from which angular or linear measurements are reckoned. Also called reference plane.

Datum Point.—Any point which can serve as a reference or base for the measurement of other quantities.

Decay.—Decrease of a radioactive substance because of nuclear emission of alpha or beta particles, positrons, or gamma rays. See radioactivity.

In beta decay, for example, the emission of a β-particle, i.e., an electron causes radioactive change into a daughter element of the same atomic weight as the parent element but of atomic number higher by 1.

218

Descending Node.—That point at which a planet, planetoid, or comet crosses to the south side of the ecliptic; that point at which a satellite crosses to the south side of the equatorial plane of its primary. Also called southbound node. The opposite is ascending node or northbound node.

Deuterium.—(symbol D, d) A heavy isotope of hydrogen having one proton and one neutron in the nucleus.

Dipole.—1. A system composed of two, separated, equal electric or magnetic charges of opposite sign. 2.=dipole antenna.

Dipole Antenna.—A straight radiator, usually fed in the center, and producing a maximum of radiation in the plane normal to its axis. The length specified is the overall length.

Common usage is micowave antennas considers a dipole to be a metal radiating structure which supports a line current distribution similar to that of a thin straight wire, a half wavelength long, so energized that the current has two nodes, one at each of the far ends.

Drag.—(symbol D). A retarding force acting upon a body in motion through a fluid, parallel to the direction of motion of the body. It is a component of the total fluid forces acting on the body.

E

Earth Satellite. — A body that orbits about the Earth; specifically, an artificial satellite placed in orbit by man.

Ecliptic.—The apparent annual path of the Sun among the stars; the intersection of the plane of the Earth's orbit with the celestial sphere.

The ecliptic is a great circle of the celestial sphere inclined at an angle of about 23°27' to the celestial equator.

Ecological System.—A habitable environment, either created artifically, as in a manned space vehicle, or occurring naturally, such as the environment on the surface of the Earth, in which, animals, or other organisms can live in mutual relationship with one another and the environment.

Ideally the environment furnishes the sustenance for life, and the resulting waste products revert or cycle back into the environment to be used again for the continuous support of life.

Ejection Capsule.—1. In an aircraft or manned spacecraft, a detachable compartment serving as a cockpit or cabin, which may be ejected as a unit and parachuted to the ground. 2. A satellite, probe, or unmanned spacecraft, a boxlike unit, usually containing recorded instruments or records of observed data, which may be ejected and returned to Earth by a parachute or other deceleration device.

E-Layer.—A division of the ionosphere, usually found at an altitude between 100 and 100 and 120 kilometers in the E-region. It exhibits one or more distinct maximums and sharp gradients of free electron density. It is most pronounced in the daytime but does not entirely disappear at night. Also called E_1- layer, Kennelly-Heaviside layer, or Heaviside layer.

There is some evidence to indicate a second layer above the normal E-layer located at about 150 kilometers, and called the E_1-layer.

Entry Corridor. — Depth of the region between two trajectories which define the design limits of a vehicle which will enter a planetary atmosphere.

Envelope.—1. Of a variable, a curve which bounds the values which the variable can assume, but does not consider possible simultaneous occurrences or correlations between different values. 2. The bounds within which a certain system can operate as a flight envelope, especially a graphic representation of these bounds showing inter-relationships of operational parameters.

Ephemeris (plural, ephemerides). A periodical publication tabulating the predicted positions of celestial bodies at regular intervals, such as daily, and containing other data of interest to the astronomers.

Epoch. — A particular instant for which certain data are valid, as the data for which an astronomical catalogue is computed.

219

Equinox.—1. One of the two points of intersection of the ecliptic and the celestial equator, occupied by the Sun when its declination is 0°. Also called equinoctial point.

That point occupied on or about March 21, when the Sun's declination changes from south to north, is called vernal equinox, March equinox, or first point of Aries; that point occupied on or about September 23, when the declination changes from north to south, is called autumnal equinox, September equinox, or first point of Libra.

Equinox is often used to mean vernal equinox, when referring to the origin of measurement of right ascention and celestial longitude.

2. That instant the Sun occupies one of the equinoctial points.

Exosphere.—The outermost, or topmost, portion of the atmosphere. Its lower boundary is the critical level of escape, variously estimated at 500 to 1000 kilometers above the Earth's surface. Also called region of escape.

Extragalactic.—Outside our galaxy, which is the Milky Way.

F

Facsimile.—In electrical communications, the process, or the result of the process, by which fixed graphic material including pictures or images is canned and the information converted into signals which are used either locally or remotely to produce in record form a likeness (facsimile) of the subject copy.

Fahrenheit Temperature Scale (abbr F).—A temperature scale with the ice point at 32° and the boiling point of water at 212°.

Conversion with the Celsius (centigrade) temperature scale (abbr C) is by the formula: F = 9/5 C + 32.

First Point of Aries.—Vernal equinox.

First Point of Cancer.—Summer solstice.

First Point of Capricornus.—Winter solstice.

First Point of Libra.—Autumnal equinox.

First Quarter.—The phase of the Moon when it is near east quadrature, when the western half of it is visible to an observer on the Earth.

Fission.—The splitting of an atomic nucleus into two more-or-less equal fragments. Fission may occur spontaneously or may be induced by capture of bombarding particles. In addition to the fission fragments, neutrons and gamma rays are usually produced during fission.

Fix.—In navigation, a relatively accurate position determined without reference to any former position. It may be classed as visual, sonic, celestial, electronic radio, hyperbolic, loran, radar, etc., depending upon the means of establishing it.

Fraunhofer Lines.—Dark lines in the absorption spectrum of solar radiation due to absorption by gases in the outer portions of the Sun and in the Earth's atmosphere.

F-Region.—The general region of the ionosphere in which the F_1-layer and F_2-layer tend to form.

Frequency Band.—A continuous range of frequencies extending between two limiting frequencies.

Specific frequency bands used in radio and radar are often designated by names, numbers, or letters. The band designations as decided upon the Atlantic City Radio Convention of 1947 and later modified by Comite Consultatif International Radio (CCIR) Recommendation No. 142 in 1953 are:

Frequency Band	Approximate Frequency Range, gigacycles			Approximate wavelength range centimeters		
P-band	0.225	to	0.39	140	to	76.9
L-band	0.39	to	1.55	76.9	to	19.3
S-band	1.55	to	5.20	19.3	to	5.77
X-band	5.20	to	10.90	5.77	to	2.75
K-band	10.90	to	36.00	2.75	to	0.834
Q-band	36.00	to	46.00	0.834	to	0.652
V-band	46.00	to	56.00	0.652	to	0.536

Note that band N extends from 0.3×10^N to 3×10^N cycles; thus band 4 designates the frequency range 0.3×10^4 to 3×10^4 cycles. The upper limit is included in each band; the lower limit is excluded.

Description of bands by means of adjectives is arbitrary and the CCIR recommends that it be discontinued.

The designation ELF, extremely low frequency, has recently been proposed for the band extending from 3 kilocycles down to 1 cycle per second. These frequencies have been used for years in the study of lightning and associated phenomena and may be useful in communicating with spacecraft.

The frequency bands used by radar (radar frequency bands) were first designated by letters for military secrecy. Those designations were:

Band No.	Frequency Range			Metric Subdivision Waves	Atlantic City frequency subdivision	
4	kc	3-	30	Myriametric	Very-low	VLF
5		30-	300	Kilometric	Low	LF
6		300-	3,000	Hectometric	Medium	MF
7		3,000-	30,000	Decametric	High	HF
	mc					
8		30-	300	Metric	Very-high	VHF
9		300	3,000	Decimetric	Ultra-high	UHF
10		3,000	30,000	Centimetric	Super- "	SHF
11		30,000	300,000	Millimetric	Extre. "	EHF
12		300,000	3,000,000	Decimillimetric	- - - -	- -

The C-band, 3.9 to 6.2 gigacycles, overlaps the S. and X-bands. These letter desingations have no official sanction.

Frequency Modulation (abbr FM). — Angle modulation of a sine-wave carrier in which the instantaneous frequency of the modulated wave differs from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave.

Combinations of phase and frequency modulation are commonly referred to as frequency modulation.

Fuel Cell.—1. A fuel tank, especially one of a number of fuel tanks, as in an airplane's wing; also, a compartment within a fuel tank. 2. A device which converts chemical energy directly into electrical energy but differing from a storage battery in that the reacting chemicals are supplied continuously as needed to meet output requirements.

G

g or G. — An acceleration equal to the acceleration of gravity, 980,665 centimeter per second-per second, approximately. 32.2 feet per second at sea level; used as a unit of stress measurement for bodies undergoing acceleration.

Gain — 1. A general term used to denote an increase in signal power in transmission from one point to another. Gain is usually expressed in decibels and is widely used to denote transducer gain. 2. An increase or amplification. In radar there are two general usuages of the term: (a) antenna gain, or gain factor, is the ratio of the power transmitted along the beam axis to that of an isotropic radiator transmitting the same total power; (b) receiver gain, or video gain, is the amplification given a signal by the receiver.

Galaxy.—A vast assemblage of stars, nebulae, etc., composing an island universe separated from other such assemblages by great distances.

The Sun and its family of planets is part of a galaxy commonly called the Milky Way. The nearest galaxy to the Milky Way is the spiral galaxy Andromeda at a distance of approximately 800,000 light years.

Gamma Ray.—A quantum of electromagnetic radiation emitted by a nucleus, each such photon being emitted as the result of a quantum transition between two energy levels of the nucleus. Gamma rays have energies usually between 10 thousand electron volts and 10 million electron volts with high frequencies. Also called gamma radiation.

X-rays occur in the same energy range as gamma rays but are of nonnuclear origin.

In atmospheric electricity, gamma rays are of some importance in contributing to atmospheric ionization, along with alpha particles and beta particles. Gamma-ray photons have much greater penetration ranges than do alpha and beta particles, often amounting to distances of the order of a hundred meters in air at sea level. These high-energy photons may initiate their ionizing action by ejecting photo-electrons from neutral atoms or molecules of the air, by ejecting electrons by the Compton effect, or (for gamma photons with energies above a few million electron volts) by pair production in which an electron and a positron are created.

Gas.—The state of matter in which the molecules are practically unrestricted by intermolecular forces so that the molecules are free to occupy any space within an enclosure.

In vacuum technology the word gas has been loosely applied to the noncondensable gas and vapor within a vacuum system.

Geocentric.—Relative to the Earth as a center; measured from the center of the Earth.

Geodesy.—The science which deals mathematically with the size and shape of the Earth, and the Earth's external gravity field, and with surveys of such precision that overall size and shape of the Earth must be taken into consideration.

Geodetic Datum.—A datum consisting of five quantities, the latitude and longitude and elevation above the reference spheroid of an initial point, a line from this point, and two constants which define the reference spheroid. Azimuth or orientation of the line, given the longitude, is determined by astronomic observations. Alternatively, the datum may be considered as three rectangular coordinates fixing the origin of a coordinate system whose orientation is determined by the fixed stars, and the reference spheroid is an arbitrary coordinate surface of an orbiting ellipsoidal coordinate system.

A geodetic datum forms the basis for the computation of horizontal control surveys in which the curvature of the Earth is considered.

Gravitation.—The acceleration produced by the mutual attraction of two masses, directed along the line joining their centers of masses, and of magnitude inversely proportional to the square of the distance between the two centers of mass.

This acceleration on a unit mass has the magnitude $G(m/r^2)$, where $\underline{m}$ is the mass of the attracting body, $\underline{r}$ is the distance between the centers of mass, and G is the gravitational constant equal to 6.670×10^{-8} cm^3/gram sec^2.

In the case of masses in the Earth's gravitational field, $\underline{m}$ is the mass of the Earth, equal to 5.975×10^{27} grams. However, the rotation of the Earth and atmosphere modifies this field to produce the field of gravity.

Great Red Spot.—An oval feature in the visible cloud surface of Jupiter, at latitude 20° to 25° S. It is about 25,000 miles long in the planet's east-west direction, and about 7000 miles wide in the north-south direction. It is often reddish in color, but may be white or grey, or nearly invisible compared to its surroundings.

The neighboring cloud matter seems to pass around it on the northern side, producing the so-called Red Spot Hollow, by which it may be detected even when the spot itself is invisible. Its rotation period averages 9 hours, 55 minutes, 38 seconds (very nearly the same as the rest of the planet), but varies enough so that through the years since its discovery in 1878 it has made more than one complete revolution with respect to the underlying planet.

Greenhouse Effect.—The healing effect exerted by the atmosphere upon the Earth by virtue of the fact that the atmosphere (mainly, its water vapor) absorbs and reemits infrared radiation. In detail: the shorter wavelengths are transmitted rather freely through the atmosphere to be absorbed at the Earth's surface. The Earth then reemits this as long-wave (infrared) terrestrial radiation, a portion of which is absorbed by the atmosphere and again emitted (see atmospheric radiation). Some of this is emitted downward back to the Earth's surface (counter radiation).

g-Suit or G-Suit.—A suit that exerts pressure on the abdomen and lower parts of the body to prevent or retard the collection of blood below the chest under positive acceleration.

H

Half Life.—The average time required for one half the atoms in a sample of radioactive element to decay.

The half life $t_{\frac{1}{2}}$ is given by

$$t_{\frac{1}{2}} = (\text{In } 2)\,\lambda$$

where λ is the decay constant.

Hard Landing.—An impact landing of a spacecraft on the surface of a planet or natural satellite destroying all equipment except possibly a very rugged package.

Heavy Cosmic-Ray Primaries.—The positively charged nuclei of elements heavier than hydrogen and helium up to atomic nuclei of iron. See cosmic rays.

These heavy atomic nuclei comprise about 1 percent of the total cosmic-ray particles and less than 4 percent of the total positive charges.

Heavy Water.—Water in which the hydrogen of water molecule consists entirely of the heavy hydrogen isotope of mass 2 (deuterium).

Written D_2O. Density, 1.1076 at 20°C. It is used as a moderator in certain types of nuclear reactors.

The term is sometimes applied to water whose deuterium content is greater than natural water.

Height (symbol h).—1. Vertical distance; the distance above some reference point or plane, as, height above sea level. See altitude. 2. The vertical dimension of anything; the distance which something extends above its foot or root, as blade height.

Helical Antenna.—An antenna used where circular polarization is required. The driven element consists of a helix supported above a ground plane.

Hertz. (abbr Hz).—The unit of frequency, cycles per second.

Hohmann Orbit.—A minimum energy transfer orbit.

Hyperbola.—An open curve with two branches, all points of which have a constant difference in distance from two fixed points called cocuses.

Hyperon.—In the classification of subatomic particles according to mass, the heaviest of such particles. Compare lepton, meson, nucleon.

Some large and highly unstable components of cosmic rays are hyperons.

Hypoxia. — Oxygen want or deficiency; any state wherein a physiologically inadequate amount of oxygen is available to, or utilized by, tissue without respect to cause or degree.

Igniter.—A device used to begin combustion, such as a spark plug in the combustion chamber of a jet engine, or a squib used to ignite the fuel in a rocket.

Inclination.—1. = magnetic dip. 2. (symbol i). The angle between the plane of an orbit and a reference plane.

The equator is the reference plane for geocentric orbits and the ecliptic is the reference plane for heliocentric orbits.

Inertial Coordinate System.—A system in which the (vector) momentum of a particle is conserved in the absence of external forces. Thus, only in an inertial system can Newton laws of motion be appropriately applied.

When relative coordinate systems are used, moving with respect to the inertial system, apparent forces arise in Newton laws, such as the coriolis force.

Inertial Guidance.—Guidance by means of the measurement and integration of acceleration from within the craft.

Inertial Navigation.—Dead reckoning performed automatically by a device which gives a continuous indication of position by integration of accelerations since leaving a starting point.

Inner Planets. The four planets nearest the Sun: Mercury, Venus, Earth, and Mars.

International Geophysical Year (abbr IGY).—By international agreement, a period during which greatly increased observation of world-wide geophysical phenomena is undertaken through the cooperative effort of participating nations. July 1957 to December 1958 was the first such year; however, precedent was set by the International Polar Years of 1882 and 1932.

Ion.—1. A charged atom or molecularly bound group of atoms: sometimes also a free electron or other charged subatomic particle.

An ion pair consists of a positive ion and a negative ion (usually an electron) having charges of the same magnitude and formed from a meutral atom or molecule by the action of radiation.

2. In atmospheric electricity, any of several types of, electrically charged submicroscopic particles normally found in the atmosphere. Atmospheric ions are of two principal types, small ions and large ions, although a class of intermediate ions has occasionally been reported.

The ionization process which forms small ions depends upon two distinct agencies, cosmic rays and radioactive emanations. Each of these consists of very energetic particles which ionize neutral air molecules by knocking out one or more planetary electrons. The resulting free electron and positively charged molecule (or atom) very quickly attach themselves to one or, at most, a small number of neutral air molecules, thereby forming new small ions. In the presence of Aitken nuclei, some of the small ions will in turn attach themselves to these nuclei, thereby creating new large ions.

The two main classes of ions differ widely in mobility. Only the highly mobile small ions contribute significantly to the electrical conductivity of the air under most conditions.

The intermediate ions and large ions are important in certain space charge effects, but are too sluggish to contribute much to conductivity. The processes of formation of ions are offset by certain processes of destruction of the ions.

3. In chemistry, atoms or specific groupings of atoms which have gained or lost one or more electrons, as the chloride ion or ammonium ion. Such ions exist in aqueous solutions and in certain crystal structures.

Ion Engine.—A reaction engine in which ions, accelerated in an electrostatic field, are used as propellant. Also called electrostatic engine.

224

Isostasy.—A supposed equality existing in vertical sections of the Earth, whereby the weight of any column from the surface of the Earth to a constant depth is approximately the same as that of any other column of equal area, the equilibrium being maintained by plastic flow of material from one part of the Earth to another.

Isotope.—1. One of several nuclides having the same number of protons in their nuclei, and hence belonging to the same element, but differing in the number of neutrons and therefore in mass number A, or in energy content (isomers). For example, $_6C_6^{12}$, $_6C_7^{13}$, and $_6C_8^{14}$ are carbon isotopes. Small quantitative differences in chemical properties exist in isotopes. 2. A radionuclide or a preparation of an element with special isotopic composition (allobar) as an article of commerce, so called because of the principal use of such materials as radioactive tracers. 3. In common usage, a synonym for nuclide (not recommended).

J

Jamming.—Intentional transmission or reradiation of radio signals in such a way as to interfere with reception of desired signals by the intended receiver.

Jetavator.—A control surface that may be moved into or against a rocket's jetstream, used to change the direction of the jet flow for thrust vector control.

Jet Engine.—1. Broadly, any engine that ejects a jet or stream of gas or fluid, obtaining all or most of its thrust by reaction to the ejection. 2. Specifically, an aircraft engine that derives all or most of its thrust by reaction to its ejection of combustion products (or heated air) in a jet and that obtains oxygen from the atmosphere for the combustion of its fuel (or outside air for heating, as in the case of the nuclear jet engine), distinguished in this sense from a rocket engine. A jet engine of this kind may have a compressor, commonly turbine-driven, to take in and compress air (turbojet), or it may be compressorless, taking in and compressing air by other means (pulsejet, ramjet).

Jodrell Bank.—The site of a large radio telescope, located near Manchester, England; by extension, the radio telescope itself. The radio telescope has a paraboloidal receiver 250 feet in diameter, 60 feet deep.

K

Kepler Laws.—The three empirical laws governing the motions of planets in their orbits, discovered by Johannes Kepler (1571 - 1630). These are: (a) the orbits of the planets are ellipses, with the sun at a common focus; (b) as a planet moves in its orbit, the line joining the planet and Sun sweeps over equal areas in equal intervals of time (also called law of equal areas); (c) the squares of the periods of revolution of any two planets are proportional to the cubes of their mean distances from the Sun.

Kilometer (abbr km). A unit of distance in the metric system.

1 kilometer = 3280.8 feet = 1093.6 yards = 1000 meters = 0.62137 statute miles = 0.53996 nautical miles.

Kinetic Energy (symbol E).— The energy which a body possesses as a consequence of its motion, defined as one-half the product of its mass m and the square of its speed v, $\frac{1}{2}mv^2$. The kinetic energy per unit volume of a fluid parcel is thus $\frac{1}{2}p\,v^2$, where p is the density and v the speed of the parcel.

For relativistic speeds the kinetic energy is given by: $E_k = mc^2 - moc^2$ where c is the velocity of light in a vacuum, mo is the rest mass, and m is the moving mass.

Knot.—A nautical mile per hour, 1.1508 statute miles per hour.

L

Lift.—(symbol L) 1. That component of the total aerodynamic force acting on a body perpendicular to the undisturbed airflow relative to the body. 2. To lift off, to take off in a vertical ascent. Said of a rocket vehicle.

Light.—Visible radiation (about 0.4 to 0.7 micron in wavelength) considered in terms of its luminous efficiency, i.e., evaluated in proportion to its ability to stimulate the sense of sight.

Light Time.— The elapsed time taken by electromagnetic radiation to travel from a celestial body to the observer at the time of observation.

The American Ephemeris and Nautical Almanac uses a light time of 498.9 seconds for 1 astronomical unit.

Light-Year.— A unit of length used in expressing stellar distances equal to the distance electromagnetic radiation travels in 1 year. 1 light-year = 9.460×10^{12} kilometers = 63,280 astronomical units = 0.3068 parsecs.

Longitude.— 1. Angular distance, along a primary great circle, from the adopted reference point; the angle between a reference plane through the polar axis and a second plane through that axis.

Lox.— 1. Liquid oxygen. Used attributively as in lox tank, lox unit. Also called loxgen. 2. To load the fuel tanks of a rocket vehicle with liquid oxygen. Hence, loxing.

Lunar Day.— 1. The duration of one rotation of the Earth on its axis, with respect to the Moon. Its average length is about 24 hours 50 minutes of mean solar time. Also called tidal day. 2. The duration of one rotation of the Moon on its axis, with respect to the Sun.

Lunar Distance.— The angle, at an observer on the Earth, between the Moon and another celestial body. This was the basis of a method formerly used to determine longitude at sea.

Lyman-Alpha-Radiation.— The radiation emitted by hydrogen at 1216 angstrom, first observed in the solar spectrum by rocket-borne spectrographs.

Lyman-alpha radiation is very important in the heating of the upper atmosphere thus affecting other atmospheric phenomena.

M

Mach = Mach Number.— Some writers use Mach as a unit of speed equivalent to a Mach number of 1.00, as a speed of Mach 3.1.

Mach number (symbols M, N Ma). — (Pronounced Mock, after Ernst Mach, 1838-1916, Austrian scientist.) A number expressing the ratio of the speed of a body or of a point on a body with respect to the surrounding air or other fluid, or the speed of a flow, to the speed of sound in the medium; the speed represented by this number.

Magnetic Declination.— In terrestrial magnetism; at any given location, the angle between the geographical meridian and the magnetic meridian; that is the angle between true north and magnetic north. Also called declination, and in navigation, variation.

Declination is either east or west according as the compass needle points to the east or west of the geographical meridian.

Lines of constant declination are called isogonic lines and the one of zero declination is called the agonic line.

Magnetic Deviation.— The angle between the magnetic meridian and the axis of a compass card, expressed in degrees east or west to indicate the direction in which the northern end of the compass card is offset from magnetic north. Also called deviation.

Magnetic Dip.— The angle between the horizontal and the direction of a line of force of the Earth's magnetic field at any point. Also called magnetic inclination, magnetic latitude, inclination, dip.

Magnetic Field.— 1. A region of space wherein any magnetic dipole would experience a magnetic force or torque; often represented as the geometric array of the imaginary magnetic lines of force that exist in relation to magnetic poles. 2. = magnetic field intensity.

Magnetic Field Intensity.— The magnetic force exerted on an imaginary unit magnetic pole placed at any specified point of space. It is a vector quantity. Its direction is taken as the direction toward which a north magnetic pole would tend to move under the influence of the field. If the force is measured in dynes and the unit pole is a cgs unit pole, the field intensity is given in oersteds. Also called magnetic intensity, magnetic field, magnetic field strength.

Magnetosphere.—The region of the Earth's atmosphere where ionized gas plays an important part in the dynamics of the atmosphere and where the geomagnetic field, therefore, plays an important role. The magnetosphere begins, by convention, at the maximum of the F layer at about 350 kilometers and extends to 10 or 15 earth radii to the boundary between the atmosphere and the interplanetary plasma on day side, 100 Earth Rao on night side.

Megacycle (abbr Mc, mc).—One million cycles; one thousand kilocycles. The term is often used as the equivalent of one million cycles per second.

Milky Way.—The galaxy to which the Sun belongs as seen at night from the Earth, the Milky Way is a faintly luminous belt of faint stars.

Missile.—Any object thrown, dropped, fired, launched, or otherwise projected with the purpose of striking a target. Short for ballistic missile, guided missile.

Missile should not be used loosely as a synonym for rocket or spacecraft.

N

NACA (abbr).—National Advisory Committee for Aeronautics. The predecessor of NASA.

NASA (abbr).—National Aeronautics and Space Administration.

Nautical Almanac.—An annual publication of the U.S. Naval Observatory and H. M. Nautical Almanac Office, Royal Greenwich Observatory, listing the Greenwich hour angle and declination of various celestial bodies to a precision of 0.1 minute of arc at hourly intervals; time of sunrise, sunset, moonrise, moonset; and other astronomical information useful to navigators. Prior to 1960 separate publications were issued by the two observatories entitled the American Nautical Almanac and the Abridged Nautical Almanac. See American Ephemeris and Nautical Almanac.

Nautical Mile.—A unit of distance used principally in navigation. For practical navigation it is usually considered the length of 1 minute of any great circle most commonly used. Also called sea mile.

Because of various lengths of the nautical mile in use throughout the world, due to differences in definition and the assumed size and shape of the Earth, the International Hydrographic Bureau in 1929 proposed a standard length of 1852 meters, which is known as the international nautical mile. This have been adopted by nearly all maritime nations. The U. S. Departments of Defense and Commerce adopted this value on July 1, 1954. With the yard-meter relationship then in use, the international nautical mile was equivalent to 6076.10333 feet. Using the yard-meter conversion factor effective July 1, 1959, the international nautical mile is equivalent to 6076.11549 international feet.

Navigation.—The practice or art of directing the movement of a craft from one point to another.

Navigation usually implies the presence of a human, a navigator, aboard the craft. Compare guidance.

Newton Laws of Motion.—A set of three fundamental postulates forming the basis of the mechanics of rigid bodies, formulated by Newton in 1687.

The first law is concerned with the principle of inertia and states that if a body in motion is not acted upon by an external force, its momentum remains constant (law of conservation of momentum). The second law asserts that the rate of change of momentum of a body is proportional to the force acting upon the body and is in the direction of the applied force. A familiar statement of this is the equation.

$$F = ma$$

where F is vector sum of the applied forces, $\underline{m}$ is the mass, and $\underline{a}$ is the vector acceleration of the body. The third law is the principle of action and reaction, stating that for every force acting upon a body there exists a corresponding force of the same magnitude exerted by the body in the opposite direction.

Noise.—1. Any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device.

When caused by natural electrical discharges in the atmosphere, noise may be called static. 2. An erratic, intermittent, or statistically random oscillation. 3. In electrical circuit analysis that portion of the unwanted signal which is

227

statistically random, as distinguished from hum, which is an unwanted signal occurring at multiples of the power-supply frequency.

If ambiguity exists as to the nature of the noise, a phrase such as acoustic noise or electric noise should be used.

Since the above definitions are not mutually exclusive, it is usually necessary to depend on context for the distinction.

Nose Cone. — The cone-shaped leading end of a rocket vehicle, consisting (a) of a chamber or chambers in which a satellite, instruments, animals, plants, or auxiliary equipment may be carried, and (b) of an outer surface built to withstand high temperatures generated by aerodynamic heating.

In a satellite vehicle, the nose cone may become the satellite itself after separating from the final stage of the rocket or it may be used to shield the satellite until orbital speed is accomplished, then separating from the satellite.

Nozzle (symbol n used as subscript). — 1. A duct, tube, pipe, spout, or the like through which a fluid is directed and from the open end of which the fluid is discharged, designed to meter the fluid or to produce a desired direction, velocity, or shape of discharge. 2. Specifically, that part of a rocket thrust chamber assembly in which the gases produced in the chamber are accelerated to high velocities.

Nucleus. — 1. The positively charged core of an atom with which is associated practically the whole mass of the atom but only a minute part of its volume.

A nucleus is composed of one or more protons and an approximately equal number of neutrons. The atomic number Z of the element indicates the number of protons in the nucleus. The mass number A of the element is the sum of the protons and neutrons.

O

Observed. — In astronomy and navigation pertaining to a value which has been measured in contrast to one which is computed.

Orbit. — 1. The path of a body or particle under the influence of a gravitational or other force. For instance, the orbit of a celestial body is its path relative to another body around which it revolves.

Orbit is commonly used to designate a closed path and trajectory to denote a path which is not closed. Thus, the trajectory of a sounding rocket, the orbit of a satellite.

2. To go around the Earth or other body in an orbit, sense 1.

Orbital Elements. — A set of parameters defining the orbit of a body attracted by a central, inverse-square force.

Orbital Period. — The interval between successive passages of a satellite through the same point in its orbit. Often called period.

Otolith. — A small calcareous concretion located in the inner ear which plays a part in the mechanism of orientation.

Otolith Organs. — Structures of the inner ear (utricle and saccule) which respond to linear acceleration and tilting.

Outer Atmosphere. — Very generally, the atmosphere at a great distance from the Earth's surface; an approximate synonym for exosphere.

Outer Planets. — The planets with orbits larger than that of Mars: Jupiter, Saturn, Uranus, Neptune and Pluto.

Output. — 1. The yield or product of an activity furnished by man, machine, or a system.

2. Power or energy delivered by an engine, generator, etc. 3. The electrical signal which emanates from a transducer and which is a function of the applied stimulus. Compare input.

Oxidizer (symbol o, used as subscript). — specifically, a substance (not necessarily containing oxygen) that supports the combustion of a fuel or propellant.

The quantity represented by the signal may be given in terms of electrical units, frequency, or time.

Ozonosphere. — The general stratum of the upper atmosphere in which there is an appreciable ozone concentration and in which ozone plays an important part in the radiation balance of the atmosphere. This region lies roughly between 10 and 50 kilometers, with maximum ozone concentration at about 20 to 25 kilometers. Also called ozone layer.

228

P

Pad.—Launch pad.

Parabola.—An open curve all points of which are equidistant from a fixed point, called the focus, and a straight line.

Parsec (abbr pc).—A unit of length equal to the distance from the Sun to a point having a heliocentric parallax of 1 second (1''), used as a measure of stellar distance. The name parsec is derived from the words parallax second. 1 parsec = pc
= 3.084 x 10^{13} kilometers
= 206,265 astronomical units
= 3.262 light-years.

Path.—1. Of a satellite, the projection of the orbital plane on the Earth's surface, the locus of the satellite subpoint.

Since the Earth is turning under the satellite, the path of a single orbital pass will not be a closed curve. Path and track are used interchangeably. On a cylindrical map projection, the path is a sine-shaped curve.
2. Of a meteor, the projection of the trajectory on the celestial sphere, as seen by the observer.
3. = flightpath.

Payload.—1. Originally, the revenue-producing portion of an aircraft's load, e.g., passengers, cargo, mail, etc. 2. By extension, that which an aircraft, rocket, or the like carries over and above what is necessary for the operation of the vehicle for its flight.

Perigee.—That orbital point nearest the Earth when the Earth is the center of attraction. See orbit.

That orbital point farthest from the Earth is called apogee. Perigee and apogee are used by some writers in referring to orbits of satellites, especially artificial satellites, around any planet or satellite, thus avoiding coinage of new terms for each planet and Moon.

Perihelion.—That point in a solar orbit which is nearest the Sun.

That orbital point farthest from the Sun is called aphelion. The term perihelion should not be confused with parhelion, a form of halo.

Period.—1. The interval needed to complete a cycle. 2. = orbital period. 3. Specifically, the interval between passages at a fixed point of a given phrase of a simple harmonic wave; the reciprocal of frequency. 4. The time interval during which the power level (flux) of a reactor changes by a factor of e (2.718, the base of natural logarithmus).

Perturbation.—1. Any departure introduced into an assumed steady state of a system, of a small departure from a nominal path such as a desired trajectory. Usually used as equivalent to small perturbation.

2. Specifically, a disturbance in the regular motion of a celestial body, the result of a force additional to that which causes the regular motion, specifically, a gravitational force.

Photon.—According to the quantum theory of radiation, the elementary quantity, or quantum, of radiant energy. It is regarded as a discrete quantity having a momentum equal to hv/c, where h is Planck constant, v is the frequency of the radiation, and c is the speed of light in a vacuum. The photon is never at rest, has no electric charge and no magnetic moment, but does have a spin moment. The energy of a photon (the unit quantum of energy) is equal to hv.

Photosphere.—The intensely bright portion of the sun visible to the unaided eye.

Planet.—A celestial body of the solar system, revolving around the Sun in a nearly circular orbit, or a similar body revolving around a star.

Plasma.—An electrically conductive gas comprised of neutral particles, ionized particles, and free electrons, but which, taken as a whole, is electrically neutral.

A plasma is further characterized by relatively large intermolecular distances, large amounts of energy stored in the internal energy levels of the particles, and the presence of a plasma sheath at all boundaries of the plasma.

Plasmas are sometimes referred to as a fourth state of matter.

Plasma Engine.—A reaction engine using magnetically accelerated plasma as propellant.

A plasma engine is a type of electrical engine.

Plasma Rocket.—A rocket using a plasma engine. Also called electromagnetic rocket.

Precession. — Change in the direction of the axis of rotation of a spinning body, as a gyro, when acted upon by a torque.

Precession in Right Ascension. — The component of general procession along the celestial equator, amounting to about 46.1 seconds of arc per year.

Precession of the Equinoxes. — The conical motion of the Earth's axis about the normal to the plane of the ecliptic, caused by the attractive force of the Sun, Moon and other planets on the equatorial protuberance of the Earth.

The effect of the Sun and Moon, called lunisolar precession, is to produce a westward motion of the equinoxes along the ecliptic. The effect of other planets, called planetary precession, tends to produce a much smaller motion eastward along the ecliptic. The resultant motion, called general precession, is westward along the ecliptic at the rate of about 50.3 seconds of arc per year. The component of general precession along the celestial equator, called precession in right ascension, is about 46.1 seconds of arc per year; and the component along a celestial meridian, called precession in declination, is about 20.0 seconds of arc per year.

Principal Planets. — The larger bodies revolving about the Sun in nearly circular orbits. See planet.

The known principal planets, in order of their distance from the Sun are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.

Propellant (symbol p, used as a subscript). — Any agent used for consumption or combustion in a rocket and from which the rocket derives its thrust, such as a fuel, oxidizer, additive catalyst, or any compound or mixture of these; specifically, a fuel, oxidant, or a combination of mixture of fuel and oxidant used in propelling a rocket. See fuel.

Proton. — A positively charged subatomic particle having a mass of 1.67252 x 10^{-24} gram, slightly less than that of a neutron but about 1836 times greater than that of an electron.

Proton-Proton Reaction. — A thermonuclear reaction in which two protons collide at very high velocities and combine to form a deutron. The resultant deutron may capture another proton to form tritium and the latter may undergo proton capture to form helium.

The proton-proton reaction is now believed to be the principal source of energy within the Sun and other stars of its class. A temperature of the order of 5 million degrees Kelvin and high hydrogen (proton) concentrations are required for this reaction to proceed at rates compatible with energy emission by such stars.

Proton Storm. — The flux of protons sent into space by a solar flare.

Q

Quantum Theory. — The theory first stated by Max Planck (before the Physical Society of Berlin on December 14, 1900) that all electromagnetic radiation is emitted and absorbed in quanta, each of magnitude hv, h being the Planck constant and v the frequency of the radiation.

Quiet Sun. — The Sun when it is free from unusual radio wave or thermal radiation such as that associated with sun spots. See IQSY.

R

Radar. — (From radio detection and ranging.) 1. A method, system, or technique of using beamed, reflected, and timed radio waves for detecting, locating, or tracking objects (such as rockets), for measuring altitude, etc., in any of various activities, such as air traffic control or guidance. 2. The electronic equipment or apparatus used to generate, transmit, receive and usually, to display radio scanning or locating waves; a radar set.

The terms primary radar and secondary radar may be used when the return signals are, respectively, by reflection and by the transmission of a second signal as a result of triggering responder beacon by the incident signal.

Radar Astronomy. — The study of celestial bodies within the solar system by means of radiation originating on Earth but reflected from the body under observation. See radio astronomy.

Radiation.—1. The process by which electromagnetic energy is propagated through free space by virtue of joint undulatory variations in the electric and magnetic fields in space. This concept is to be distinguished from conduction and convection.

A group of physical principles known as the radiation laws comprise, to a large extent, the current state of practical knowledge of the complex radiative processes.

2. The process by which energy is propagated through any medium by virtue of the wave motion of that medium, as in the propagation of sound waves through the atmosphere, or ocean waves along the water service. 3. = radiant energy. 4. = electromagnetic radiation, specifically, high-energy radiation such as gamma rays and X-rays. 5. Corpuscular emissions, such as α or β-radiation. 6 = nuclear radiation. 7. = radioactivity.

Radiation Belt.—An envelope of charged particles trapped in the magnetic field of a spatial body. See Van Allen belt.

Radiation Cooled.—Of a structure, pertaining to the use of materials able to radiate heat at a rate such that the rate of increase of the temperature of the material is low.

Radiation Sickness.—A syndrome following intense acute exposure to ionizing radiations. It is characterized by nausea and vomiting a few hours after exposure. Further symptoms include bloody diarrhea, hemorrhage under the skin, and internally epilation (hair falling), and a decrease in blood-cell level.

Radioactivity.—1. Spontaneous disintegration of atomic nuclei with emission of corpuscular or electromagnetic radiations.

The principal types of radioactivity are alpha decay, beta decay, and isomeric transition.

To be considered as radioactive a process must have a measureable lifetime between approximately 10^{-10} second and approximately 10^{17} years. Radiations emitted within a time too short for measurement are called prompt.

Prompt radiations such as gamma rays and X-rays are often associated with radioactive disintegrations.

2. The number of spontaneous disintegrations per unit mass and per unit time of a given unstable (radioactive) element, usually measured in curies.

Radio Astronomy.—1. The study of celestial objects through observation of radio-frequency waves emitted or reflected by these objects.

In this sense radio astronomy includes both the use of radiation emitted by the celestial bodies and of radiation originating on Earth and reflected by celestial bodies (radar and astronomy).

2. Specifically, the study of celestial objects by measurement of the radiation emitted by them in the radiofrequency range of the electromagnetic spectrum.

Radio astronomy measurements are usually of the intensity of the received signal but often include polarization of the signal and angular size of the source.

Rate Gyro.—A single-degree-of-freedom gyro having primarily elastic restraint of its spin axis about the output axis. In this gyro an output signal is produced by gimbal angular displacement, relative to the base, which is proportional to the angular rate of the base about the input axis.

Rate Integrating Gyro.—A single-degree-of freedom gyro having primarily viscous restraint of its spin axis about the output axis. In this gyro an output signal is produced by gimbal angular displacement, relative to the base, which is proportional to the integral of the angular rate of the base about the input axis.

Readout.—1. The action of a radio transmitter transmitting data either instantaneously with the acquisition of the data or by playing of a magnetic tape upon which the data have been recorded. 2. The data transmitted by the action described in sense 1. 3. In computer operations, to extract information from storage.

Readout Station.—A recording or receiving radio station at which data are received from a transmitter in a probe, satellite, or other spacecraft.

Real Time.—Time in which reporting on events or recording of events is simultaneous with the events.

For example, the real time of a satellite is that time in which it simultaneously ports its environment as it encounters it; the real time of a computer is that time during which it is accepting data.

Real-Time Data.—Data presented in usable form at essentially the same time the event occurs.

The delay in presenting the data must be small enough to allow a corrective action to be taken if required.

Red Shift.—In astronomy, the displacement of observed spectral lines toward the longer wavelengths of the red end of the spectrum. The term red shift is applied both to the Doppler effect caused by the relative speed of recession of the observed body and the gravitation or relativestic shift in which the frequency of light emitted by atoms in stellar atmospheres decreased by a factor proportional to the mass-radius relationship of the star.

Reentry.—The event occurring when a spacecraft or other object comes back into the sensible atmosphere after being rocketed to higher altitudes; the action involved in this event.

Retrograde Motion.—1. Motion in an orbit opposite to the usual orbital direction of celestial bodies within a given system. Specifically, of a satellite, motion in a direction opposite to the direction of rotation of the primary. 2. The apparent motion of a planet westward among the stars. Also called retrogression.

Retrorocket.—(From retroacting.) A rocket fitted on or in a spacecraft, satellite, or the like to produce thrust opposed to forward motion.

Revolution.—1. Motion of a celestial body in its orbit; circular motion about an axis usually external to the body.
In some contexts, the terms revolution and rotation are used interchangeable but, with reference to the motions of a celestial body, revolution refers to motion in an orbit or about an axis external to the body, whereas rotation refers to motion about an axis within the body. Thus, the Earth revolves about the Sun annually and rotates about its axis daily.

Right Ascension.—Angular distance east of the vernal equinox; the arc of the celestial equator, or the angle at the celestial pole, between the hour circle of the vernal equinox and the hour circle of a point on the celestial sphere, measured eastward from the hour circle of the vernal equinox through 24 hours.
Angular distance west of the vernal equinox, through 360°, is sidereal hour angle.

Roentgen.—A unit of radiation, that quantity of X-rays or gamma rays which will produce, as a consequence of ionization, 1 electrostatic unit of electricity in 1 cubic centimeter of dry air measured at 0° C and standard atmospheric pressure.

Roentgen-Equivalent-Man (abbr rem).— A unit of radiation which when absorbed by a human being, produces the same effect as the absorption of 1 roentgen of high-voltage X-rays.

Roll.—1. The act of rolling; rotational or oscillatory movement of an aircraft or similar body about a longitudinal axis through the body-called roll for any degree of such rotation. 2. The amount of this movement, i.e., the angle of roll.

Rotation.—1. Turning of a body about an axis within the body, as the daily rotation of the Earth. See revolution. 2. One turn of a body about an internal axis, as a rotation of the Earth.

S

Satellite.—1. An attendant body that revolves about another body, the primary; especially in the solar sytem, a secondary body, or Moon, that revolves about a planet. 2. A manmade object that revolves about a spatial body, such as Explorer I orbiting about the Earth. 3. Such a body intended and designed for orbiting, as distinguished from a companion body that may incidentally also orbit, as in the observer actually saw the orbiting rocket rather than the satellite. 4. An object not yet placed in orbit, but designed or expected to be launched into an orbit.

S-Band.—A frequency band used in radar extending approximately from 1.55 to 5.2 kilomegacycles per second.

Secor (abbr).—Sequential collation of range.

Skin.—The covering of a body, of whatever material, such as the covering of a fuselage, of a wing, of a hull, of an entire aircraft, etc.; a body shell, as of a rocket; the surface of a body.

Soft Landing.—The act of landing on the surface of a planet without damage to any portion of the vehicle or payload except possibly the landing gear.

Solar Wind.—Streams of plasma flowing approximately radially outward from the Sun.

Sounding Rocket.—A rocket that carries aloft equipment for making observations of or from the upper atmosphere.

Space.—1. Specifically, the part of the universe lying outside the limits of the Earth's atmosphere. 2. More generally, the volume in which all celestial bodies, including the Earth, move.

Spin Stabilization.—Directional stability of a spacecraft obtained by the action of gyroscopic forces which result from spinning the body about its axis of symmetry.

State of the Art.—The level to which technology and science have at any designated cutoff time been developed in a given industry or group of industries.

Stationary Orbit.—An orbit in which the satellite revolves about the primary at the angular rate at which the primary rotates on its axis. From the primary, the satellite thus appears to be stationary over a point on the primary.

A stationary orbit with respect to the Earth is commonly called a 24-hour orbit.

Stellar Guidance.—Celestial guidance.

Stellar Inertial Guidance.—The guidance of a flight-borne vehicle by a combination of celestial and inertial guidance; the equipment which accomplishes the guidance.

Strain Gage.—An instrument used to measure the strain or distortion in a member or test specimen (such as a structural part) subjected to a force.

Sunspot Cycle.—A cycle with an average length of 11.1 years but varying between about 7 and 17 years in the number and area of sunspots, as given by the relative sunspot number. This number rises from a minimum of 0 to 10 to a maximum of 50 to 140 about 4 years later, and then declines more slowly.

An approximate 11-year cycle has been found or suggested in geomagnetism, frequency of aurora, and other ionospheric characteristics. The u-index of geomagnetic intensity variation shows one of the strongest known correlations to solar activity.

Eleven-year cycles have been suggested for various tropospheric phenomena, but none of these has been substantiated.

Telemeter.—1. To measure at a distance. See telemetering, telemetry. 2. The electronic unit which transmits the signal in a telemetering system.

Telemetering.—1. A measurement accomplished with the aid of intermediate means which allows perception, recording, or interpretation of data at a distance from a primary sensor.

The most widely employed interpretation of telemetering restricts its significance to data transmitted by means of electromagnetic propagation.

2. Automatic radio communication intended to indicate or record a measurable variable quantity at a distance.

Telemetry.—The science of measuring a quantity or quantities, transmitting the results to a distant station, and there interpreting, indicating, and/or recording the quantities measured.

Temperature.—1. In general, the intensity of heat as measured on some definite temperature scale by means of any of various types of thermometers. 2. In statistical mechanics, a measure of translational molecular kinetic energy (with three degrees of freedom). 3. In thermodynamics, the integrating factor of the differential equation referred to as the first law of thermodynamics.

Thrust.—1. The pushing or pulling force developed by an aircraft engine or a rocket engine. 2. The force exerted in any direction by a fluid jet or by a powered screw, as, the thrust of an antitorque rotor. 3. (symbol F). Specifically, in rocketry, $F = mv$ where $\underline{m}$ is propellant mass flow and v is exhaust velocity relative to the vehicle. Also called momentum thrust.

Track.—1. The path or actual line of movement of an aircraft, rocket, etc., over the surface of the Earth. It is the projection of the flight-path on the surface. 2. To observe or plot the path of something moving, such as an aircraft or rocket, by one means or another, as by telescope or by radar—said of persons or of electronic equipment, as the observer, or the radar, tracked the satellite. 3. To follow a desired track.

Tropopause.— The boundary between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate. The change is in the direction of increased atmospheric stability from regions below to regions above the tropopause. Its height varies from 15 to 20 kilometers in the tropics to about 10 kilometers in polar regions. In polar regions in winter it is often difficult or impossible to determine just where the tropopause lies, since under some conditions there is no abrupt change in lapse rate at any height.

Troposphere.— That portion of the atmosphere from the Earth's surface to the stratosphere; that is, the lowest 10 to 20 kilometers of the atmosphere. The troposphere is characterized by decreasing temperature with height, appreciable vertical wind motion, appreciable water-vapor content, and weather. Dynamically, the troposphere can be divided into the following layers: surface boundary layer, Ekman layer, and free atmosphere.

Turbo Jet Engine.— A jet engine incorporating a turbine-driven air compressor to take in and compress the air for the combustion of fuel (or for heating by a nuclear reactor), the gases of combustion (or the heated air) being used both to rotate the turbine and to create a thrust-producing jet. Often called a turbojet.

U

Umbilical Cord.— Any of the servicing electrical or fluid lines between the ground or a tower and an uprighted rocket vehicle before the launch. Often shortened to umbilical.

Unidirectional Antenna.— An antenna which has a single well-defined direction of maximum gain.

Universe.— In statistical terminology, = population.

V

Vacuum.— 1. A given space filled with gas at pressures below atmospheric pressure. Various approximate ranges are:

low vacuum, torr	760 to 25
medium vacuum, torr	25 to 10^{-3}
high vacuum, torr	10^{-3} to 10^{-6}
very high vacuum, torr	10^{-6} to 10^{-9}
ultrahigh vacuum, torr	10^{-9} and below

2. In reference to satellite orbital parameters, without consideration of the perturbing effects of an atmosphere, as in vacuum perigee, vacuum apogee.

Van Allen Belt, Van Allen Radiation Belt.— (For James A. Van Allen, 1915-.) The zone of high-intensity particulate radiation surrounding the Earth beginning at altitudes of approximately 1000 kilometers.

The radiation of the Van Allen Belt is composed of protons and electrons temporarily trapped in the Earth's magnetic field. The intensity of radiation varies with the distance from the Earth.

Velocity of Escape.— The initial speed as object, particularly a molecule of gas, must have at the surface of a celestial body to overcome the gravitational pull and proceed out into space without returning to the celestial body. Also called escape velocity, escape speed.

The velocity of escape determines a body's ability to retain an atmosphere. The velocity of escape on the surface of the Earth is nearly 7 miles per second, neglecting air resistance.

Vernal Equinox.— 1. That point of intersection of the ecliptic and the celestial equator, occupied by the Sun as it changes from south to north declination, on or about March 21. Also called March equinox, first point of Aries. 2. That instant the Sun reaches the point of zero declination when crossing the celestial equator from south to north.

Visible Spectrum.— That portion of the electromagnetic spectrum occupied by the wavelengths of visible radiation, roughly 4000 to 7000 angstroms. This portion of the electromagnetic spectrum is bounded on the short-wavelength end by ultra-violet radiation, and on the long-wavelength end by infrared radiation.

W

Warhead.— Originally the part of a missile carrying the explosive, chemical, or other charge intended to damage the enemy. By extension, the term is sometimes used as synonymous with payload or nose cone.

Window.— 1. Any device introduced into the atmosphere for producing an appreciable radar echo, usually for tracking some airborne device or as a tracer of wind. 2. A World War II code name for a type of radar-jamming device employed to confuse the operators of enemy radars (also referred to by the code names of rope, chaff, and clutter).

One type of window consists of packages containing thousands of small strips of paper-backed tinfoil which may be dropped from aircraft and balloons. The packages burst open upon ejection, scattering the tinfoil widely, producing a radar echo which looks like a small shower or a tight formation of aircraft on plan-position-indicator scopes.

3. Any gap in a linear continuum, as atmospheric windows, ranges of wavelengths in the electromagnetic spectrum to which the atmosphere is transparent, or firing windows, intervals of time during which conditions are favorable for launching a spacecraft on a specific mission.

Winter Solstice.—1. That point on the ecliptic occupied by the Sun at maximum southerly declination. Sometimes called December solstice, first point of Capricornus. 2. That instant at which the Sun reaches the point of maximum southerly declination, about December 22.

X

X-Band.—A frequency band used in radar extending approximately from 5.2 to 10.9 kilomegacycles per second.

X-Ray.—Nonnuclear electromagnetic radiation of very short wavelength, lying within the interval of 0.1 to 100 angstroms (between gamma rays and ultraviolet radiation). Also called X-radiation, Reoentgen ray.

X-rays penetrate various thicknesses of all solids and they act upon photographic plates in the same manner as light. Secondary X-rays are absorbed by a substance; in the case of absorption by a gas, this results in ionization.

Y

Yagi Antenna.—A type of directional antenna used on some types of radar and radio equipment consisting of an array of elemental, single-wire dipole antennas and reflectors.

Yaw.—1. The rotational or oscillatory movement of an aircraft, rocket, or the like about a vertical axis. 2. The amount of this movement, i.e., the angle of yaw. 3. To cause to rotate about a vertical axis. 4. To rotate or oscillate about a vertical axis.

Z

Zenith.—That point of the celestial sphere vertically overhead.

The point 180° from the zenith is called the nadir.

Zero-G.—Weightlessness.

Zero Launch.—The launch of a rocket or aircraft by a zero-length launcher.

Zero-Length Launcher.—A launcher that holds a vehicle in position and releases the rocket simultaneously at two points so that the buildup of thrust, normally rocket thrust, is sufficient to take the missile or vehicle directly into the air without need of a take-off run and without imposing a pitch rate release.

The term is not normally applied to a pad used for a vertical launch.

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